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Risk associated with occurrence of toxic elements in the environment surrounding landfills in An Giang Province, Vietnam

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Abstract: The study aimed to evaluate the concentration of potentially toxic elements in the soil samples of landfill sites in An Giang province. Eighty-eight soil samples were collected from five landfills. The potentially toxic elements including Cu, Zn, Pb, Cd, and As were analysed and compared with the National technical regulations on the allowable limits of heavy metals in the soils. A cluster analysis was applied to identify the sampling sites with similar soil toxic elements properties. The ecological potential risk index was used to determine the risk of the landfills to the ecosystem. The results showed that four out of five potentially toxic elements were detected in the soil, and their concentration decreased in the order of Zn > Cu > Pb > As. Most of the potentially toxic element concentrations were within the allowable limits, except for Cu and As in some positions. The ecological potential risk index in unsanitary landfills was higher than that in a sanitary landfill; however, the level of risk was low. The occurrence of toxic elements in the soil around the landfills affects the ecosystems as well as human health. Therefore, it is necessary to prevent the effect of heavy metals in the surrounding environments.

Keywords: cluster analysis; ecological potential risk; ecosystem; human health; sanitary landfill

Due to the rapid economic, population growth, and urbanisation, waste generation has doubled in less than 15 years in Vietnam (World Bank 2018). The total waste generated in 2015 was estimated to be over 27 million tonnes, with a predicted municipal solid waste generation of 8.4% per year for urban areas. As a result, the total waste volume in Vietnam will be about 54 million tonnes by 2030 (World Bank 2018). Solid waste can be accumulated underground for a long time, causing potential hazards to the environment. Moreover, heavy metal-contaminated waste, such as lead, copper, nickel, and cadmium, could accumulate in the soil, vegetables, and water sources, consequently ending up the human body via the food chain. In addition, chemicals and microorganisms from solid waste are readily dispersed into the surrounding environments (Ministry of Natural Resources and Environment 2011). Most of the landfills in the Mekong Delta have not been designed to meet the standards of sanitary landfills (Hoang et al. 2014). In Vietnam, there are currently 660 landfills that receive 20 200 tonnes of waste per day, of which only about 30% of the landfills are classified as sanitary landfills (World Bank 2018).

In An Giang province, about 1 179.49 tonnes of domestic waste is generated every day, which includes about 649.26 t/day in urban areas (accounting for 55%) and about 530.23 t/day in rural areas (accounting for 45%). Among the 36 landfills that operate in the province, three landfills are in concentrated treatment areas with hygienic burial methods. The remaining 33 landfills are open-dumping and unsanitary landfills which were often reported as causing environmental pollution. Organic waste, inorganic waste, and even hazardous waste from different sources are buried in one place. Besides, the amount of generated leachate contains high contents of organic matter and nutrients (Ding et al. 2001; Feher et al. 2016; Giao 2020). In addition, the leachate contains many heavy metals such as Zn, Ni, Cr, Cu, Pb, Hg, and some toxic organic substances, such as pesticides and polychlorinated biphenyls (PCBs) (Fauziah & Agamuth 1970; Ha 2018; Nhien & Giao 2019). The leachate, in the long term, will seep into the groundwater; therefore, if this leachate is treated improperly, it will pollute the environment. According to Fauziah and Agamuthu (1970), heavy metal pollution around landfill sites is a significant threat to the environment and public health. Unlike organic pollutants, these metals are non-biodegradable, can disperse and accumulate in ecosystems and eventually in humans via the food chain (Klinsawathom et al. 2017; Rashed 2018). The study is conducted to assess the potentially toxic element concentrations in landfill areas in An Giang province and evaluate the risk of these elements on the ecosystem. The results could provide helpful information for local environmental managers to respond to the current landfill management practices in An Giang province.

MATERIAL AND METHODS

Description of the study area. An Giang is located in the critical economic region of the Mekong Delta. The total population of the province ranked 8th in the country with 2 164 200 people in 2019. It has 3 536.7 km^2, equalling 1.03% of the country's area. The province has 11 administrative units, including 3 cities and 8 districts. The climate of An Giang province is characterised as tropical monsoon, and the average air temperature ranges from 26.3 °C to 30.1 °C. The average rainfall is about 1 500 mm per year and starts in May and ends in November; the total rain in this period accounts for 90% of the annual rainfall.

The Long Xuyen solid waste treatment complex is located in the Chau Thanh district with a scale of 4.80 ha with a 245 t/day capacity. It is currently collecting for the Long Xuyen city cluster, the Chau Thanh and Tan Chau districts with a total collected and processed volume of about 270 t/day. The Kenh 10 waste treatment area (Chau Doc city), receives 120 t/day, has a treatment capacity of 200 t/day with an area of 1.16 ha and currently treats solid waste for the Chau Doc and An Phu town clusters. The landfill in Nui Sap (Thoai Son district) was shut down in April 2018. The landfill in My Luong (Cho Moi district) has a scale of 0.7 ha, receiving 42.67 t per day. Currently, the dump is overloaded, and the Kien An landfill (Cho Moi district) receives 24 t/day with a 1 ha scale. These two landfills are still operating with the primary burial and burning method. The three above landfills are open-dumping landfills; the collected solid waste is mainly dumped and is then sprayed with chemicals. The solid waste is burned in the dry season to reduce the volume to receive more solid waste. It can be seen that the landfills have an improper solid waste management system that can lead to environmental risk.

Soil sampling and analysis. Potentially toxic element concentrations were assessed at five landfills that receive a relatively large amount of solid waste, including the Long Xuyen cluster solid waste treatment complex (R01), the Kenh 10 solid waste treatment area (R02), the Nui Sap landfill (R03), the My Luong landfill (R04), and the Kien An Commune Landfill (R05). These sampling locations are presented in Figure 1.

In total, 88 topsoil samples from a depth of less than 30 cm were collected. Twenty soil samples were collected at the R01 site (symbol S1–S20) which includes: in the landfill sites (S1, S2, S3, S4, S5, S6, S7, S9, S11, S13, S15, S17, S19) and around the waste treatment area (S8, S10, S12, S14, S16, S18 and S20). At site R02, sixteen soil samples were collected (symbol S21–S36): at the edges of the landfill (S21–S25), around the waste treatment area (S26–S30), and far from the landfill (S31–S36). At site R03, sixteen soil samples were collected and denoted as S37–S52. At the landfill R04, twelve soil samples were collected (designated S53–S64) that includes: two samples at the landfill (S57, S58) and the rest from around the landfill (S53–S56, and S59–S64). Twenty-four soil samples were collected at site R05 (designated S65–S88), including one location at the landfill (S66) and 23 points around the landfill.

One kg was collected for each soil sample which were kept in separate bags and carefully labelled. For the gravimetric analysis using specialised steel cylinders, a 100 cm^3 volume was stored in 2–3 layers of plastic bags and then transported to the laboratory. The sampling method and sample preservation were processed according to guidance on the sampling of soil (TCVN 7538-2:2005) and the preservation and handling of sludge and sediment samples (TCVN 6663-15:2004). Five potentially toxic elements, including Cu, Zn, Pb, Cd, and As, were analysed. The sample analysis methods are shown in Table 1.

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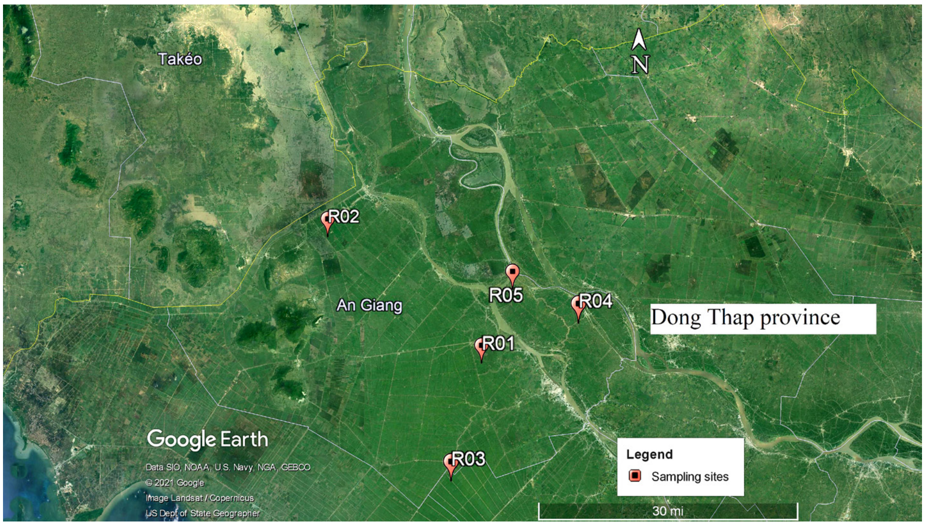

Figure 1. Location of the landfill sites in An Giang province

Table 1. Sample analysis methods and allowable limits for the risky elements

No.	Risky elements (mg/kg)	Analytical methods	QCVN 03-MT:2015/BTNMT[1]
1	Cu	flame and electrothermal atomic absorption spectrometric methods – extract dry soil samples by hydrochloric and nitric acid	100
2	Zn		200
3	Pb		70
4	Cd		2
5	As	atomic absorption spectroscopy – extract dry soil samples by hydrochloric and nitric acid	15

[1]National technical regulation on the allowable limits of heavy metals in soils

Data analysis. The concentrations of the potentially toxic elements were compared with the national technical regulation – QCVN 03-MT:2015/BTNMT (Table 1). A cluster analysis (CA) was applied to group the sampling points based on the soil environment monitoring components (Liu et al. 2013). The sampling sites were grouped into clusters based on their similarities (Feher et al. 2016; Chounlamany et al. 2017). The cluster analysis was performed using Ward's method and the results were presented in a dendrogram (Salah et al. 2012). The CA was performed using Primer (Ver. 5.2) for Windows software (PRIMER-E Ltd, Plymouth, U.K.).

The ecological potential risk index (RI) method was proposed by Hakanson (1980) to assess the potentially toxic element pollution. The RI can reflect the individual possible ecological risk level of a potentially toxic element and the overall risk level of an object (Table 2) (Hakanson 1980; Deng et al. 2010). The toxicity coefficients of Cu, Zn, Pb, Cd, and As were determined to be 5, 1, 5, 30, and 10, respectively (Hakanson 1980). The RI was chosen, according to the following Equations (1), (2), and (3):

$$\mathrm{RI} = \sum_{p=1}^{n} (E_r^p) \tag{1}$$

$$E_r^p = CF^p \times T_r^p \tag{2}$$

$$CF = \frac{C_m}{C_b} \tag{3}$$

where:
E_r^p – the potential ecological risk index for each metal;
CF – the pollutant factor of each metal;
T_r^p – the metal toxicity coefficient;

Table 2. Assessment of potential ecological risk

Risk level	E_r	RI
Low	< 40	RI < 150
Moderate	$40 \leq E_r < 80$	150 ≤ RI <30
Worrisome	$80 \leq E_r < 160$	300 ≤ RI <600
High	$160 \leq E_r < 320$	–
Very high	≥ 320	RI ≥ 600

E_r – the risk factor for the individual elements; RI – the sum of the risk factors (Hakanson 1980)

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C_m – the average concentration of metal observed;

C_b – the corresponding background value of the metal (Cu = 19.78; Zn = 47.16; Pb = 15; As = 1.9) (Turekian & Wedepohl 1961; Department of Natural Resources and Environment of An Giang province 2020; Rudnick & Gao 2003).

RESULTS AND DISCUSSION

Information about the landfill sites in An Giang province. In An Giang province, there are a total of 36 landfills, including three sanitary landfills in three concentrated treatment areas, and 19 landfills (including three district landfills and 16 commune landfills) in operation (Table 3); fourteen landfills have been discontinued (including six districts and eight commune landfills) (Table 4).

Most of the daily generated domestic solid waste is sent to three sanitary landfills in Chau Doc, Chau Thanh, and Phu Tan districts, about 480 t/day. The waste treatment area in Binh Hoa commune-Chau Thanh district has a capacity of 245 t/day, currently treating the Long Xuyen city cluster including eleven wards and two communes with a collection volume of about 173.88 t/day, the Chau Thanh district including one town and twelve communes collecting 41.67 t per day, and the Chau Phu district including one town and twelve communes with a collection volume of about 49.68 t/day. The waste treatment area includes two burial cells and one wastewater treatment area, operating with a capacity of 50 m^3/day. The waste treatment area Kenh 10 – Chau Doc, run by the An Giang Urban Environment Joint Stock Company since 2010, has the ability to process 200 t/day. The total waste collected and treated there is 120 t/day with two landfill cells, which is now treating garbage for the Chau Doc town cluster and the An Phu district. The Phu Thanh solid waste treatment area – Phu

Table 3. Current status of the landfills in An Giang province

No.	Name of the landfill	Location	Area (ha)	Amount of waste (t/day)
Centralised waste treatment				
1.1	solid waste treatment complex in Long Xuyen cluster	Chau Thanh	4.80	270
1.2	solid waste treatment plant at Kenh 10	Chau Doc	1.16	120
1.3	solid waste treatment plant at Phu Thanh	Phu Tan	2.24	100
Operating landfills				
2.1	landfill in My Luong	Cho Moi	0.70	42.67
2.2	landfill in My Hoi Dong	Cho Moi	0.25	8.5
2.3	landfill in Nhon My	Cho Moi	0.46	5
2.4	landfill in Kien Thanh	Cho Moi	0.37	10.58
2.5	landfill in Long Dien A	Cho Moi	0.20	1–3
2.6	landfill in My An	Cho Moi	0.20	2
2.7	landfill in Kien An	Cho Moi	1.00	24
2.8	waste treatment plant in My Hiep	Cho Moi	0.17	8
2.9	waste treatment plant in Hoa Binh	Cho Moi	0.17	1–3
2.10	landfill in Phu Huu	An Phu	0.29	2.5
2.11	waste treatment plant in Vinh Loc	An Phu	0.30	3.5
2.12	waste treatment plant in Vinh Hoa	Tan Chau	0.50	6
2.13	landfill in Tan Phu	Chau Thanh	0.80	1.5
2.14	landfill in Vinh Nhuan	Chau Thanh	0.25	1–2
2.15	waste treatment plant in Binh Thanh	Chau Thanh	0.32	1–2
2.16	landfill in An Cu	Tinh Bien	3.14	42–45
2.17	landfill in An Tuc	Tri Ton	1.60	38.1
2.18	waste treatment plant in Thoai Son	Thoai Son	0.025	0.63
2.19	waste treatment plant in Vinh Phu	Thoai Son	0.33	3

Source: People's Committee of An Giang Province (2016)

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Table 4. Current status of the decommissioned landfills

No.	Name of the landfill	Location	Year of start	Area (ha)	Year of stop operation
1	Binh Duc landfill	Long Xuyen	1983		6/2010
2	landfill at Cho Moi	Cho Moi	1995	0.51	3/2019
3	landfill at An Thanh Trung	Cho Moi	2012	0.067	2016
4	landfill ad Hoi An	Cho Moi	2012	0.38	6/2020
5	landfill at Tan Chau	Tan Chau	1997	1.38	19/10/2016
6	landfill at Phu My	Phu Tan	1995	1.36	3/2018
7	landfill at Phu Binh	Phu Tan	2013	0.278	9/2014
8	landfill and Hoa Binh	Chau Thanh	1998	1.1	2016
9	treatment plant ABT at An Hao	Tinh Bien	2010	0.81	4/1/2019
10	landfill at Tan Tuyen	Tri Ton	2008	0.03	2017
11	landfill at O Lam	Tri Ton	2016	0.4	2017
12	landfill at Ba Chuc	Tri Ton	2014	0.6	2018
13	landfill at Luong Phi	Tri Ton	2014	0.1	2018
14	landfill at Nui Sap	Thoai Son	1998	1.77	4/2018

Source: People's Committee of An Giang Province (2016)

Tan district run by the An Giang Urban Environment Joint Stock Company has a capacity of 200 t per day. The total amount of collection and treatment is about 94.67 t/day there. Nineteen dumping sites operate throughout the province (including three at the district level and sixteen at the commune level). The total volume of receiving and treating waste is about 365.6 t/day. In addition to three landfills in three treatment areas designed for hygienic burial, nineteen active and closed landfills are open-dump and unsanitary landfills.

The estimated composition of the domestic solid waste in An Giang province. Sources of municipal solid waste in the province arise from residential areas, agencies, schools, service areas, markets, tourism, streets, parks, and bus stations, among others. The volume and the composition of the generated daily waste depends on each site, population, living conditions, and the characteristics of people. The composition of domestic solid waste at some locations across the country is presented in Table 5.

Due to the urbanisation, changing living conditions, and habits, the composition of the domestic solid waste is made up of different proportions, organic waste is the most significant proportion of the total waste. As can be seen in Figure 2, the domestic solid waste in the province is divided into nine groups: organic matter (72.45%), paper (4.83%), metal (1.02%),

Table 5. Composition of the domestic solid waste (%)

Composition	Vietnamese Mekong Delta area	Ha Noi	Hai Phong
Organics	50.2–68.9	51.9	46.0–49.8
Plastic	3.4–10.6	3.0	12.2–14.2
Paper	3.3–6.6	2.7	3.8–4.2
Metals	1.4–4.9	0.9	0.1–0.2
Glass	0.5–2.0	0.5	0.8–0.9
Inert	14.9–28.2	38.0	23.9–24.7
Rubber and leather	0.0–5.0	1.3	0.6
Plant and animal tissue	1.5–2.5	–	–
Hazardous substance	0.0–1.0	–	–
Other	–	textile: 1.6	8.6–10.5

Source: World Bank (2018)

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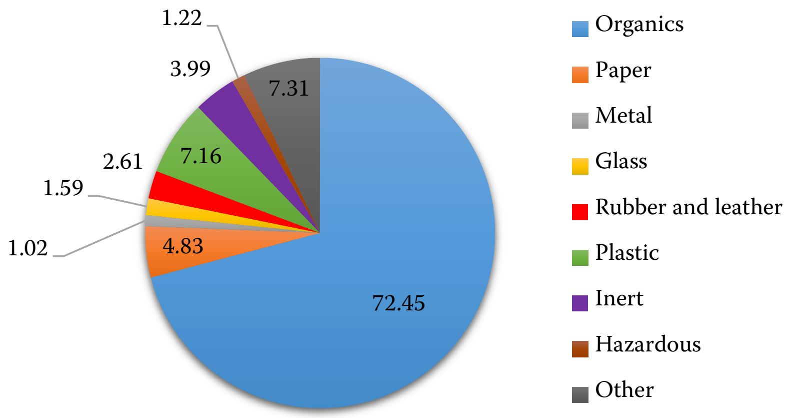

Figure 2. Estimated composition of the domestic solid waste in An Giang province (%) (Ngan 2019)

glass (1.59%), fabric-leather (2.61%), plastic (7.16%), brick-ceramic (3.99%), hazardous (1.22%) and others (7.31%). The organic substances that contain easily degradable components account for the highest proportion of the domestic solid waste composition. When a classification is conducted, the organic matter can be used as compost, which reduces the waste to be buried. The metal waste group accounts for the lowest proportion of the total domestic solid waste components. When the group of hazardous waste is classified, collected, and treated separately, it will reduce the risk of spreading and accumulating toxic substances in the environment and affecting the public health and ecosystems.

The concentration of toxic soil elements of the landfill site in An Giang province. The results showed that four out of five potentially toxic elements were detected in the soil samples at the monitored sites. The average potentially toxic element content is in a descending order of Zn > Cu > Pb > As. The concentration of these elements in the soil samples is generally within the allowable limits of the QCVN 03-MT:2015/BTNMT standard. However, potentially toxic element concentrations tend to be high in open-dumping landfills, reflecting the improper waste management and treatment, which creates a potential risk of accumulating toxic substances.

In Figure 3A, the Cu concentration at R01 varied from 16.58–36.10 mg/kg, in which there were three monitoring sites with different Cu concentrations from the remaining sites. The concentration of Cu at R02 ranged from 3.17–23.42 mg/kg. The Cu concentration at R03 fluctuated between the range of 13.24–31.16 mg/kg, in which one monitoring site had a different Cu concentration from the rest of the sites. The Cu concentrations at R04 and R05 ranged from 13.54–24.46 and 6.45–182.20 mg/kg, respectively. There were three monitoring sites with different Cu concentrations compared to the remaining locations in R05, which also had Cu concentrations exceeding the permissible limit QCVN 03-MT:2015/BTNMT. One of the five landfills, with the highest Cu concentration, where the collected waste is mainly dumped and burned is under the risk of high pollutant accumulation in the soil. In a previous study by Klinsawathom et al. (2017), the Cu concentration in soil samples in the landfill area ranged from 26.08 ± 0.06 to 69.02 ± 3.84 mg/kg, arising from alloy waste, electrical wires, and cooking utensils. In the case of the Pilsen area (Czech Republic), the landfill received different types of waste from urban areas had Cu concentration ranges from 32.43 to 58.63 mg/kg (Adamcová et al. 2016). In general, the soil at five landfills had a Cu concentration within the permissible limit, except for three locations (S67, S71, S86). The Cu concentration in these locations was 1.75 (S67), 1.82 (S71), and 1.1 (S86) times higher than the permissible limit.

In Figure 3B, the Zn concentration at R01 ranged from 34.79 to 92.72 mg/kg, where there were 3/20 monitoring sites with different Zn concentrations from the rest of the sites. Zn concentration at R02 varied from 19.76 to 87.66 mg/kg. The Zn concentrations at R03, R04, and R05 varied from 40.87 to 111.30 mg/kg, 43.41 to 70.54 mg/kg, and 25.78 to 71.22 mg/kg, respectively. As presented in Table 6, the Zn concentration is relatively high, and the highest Zn concentration was found at the closed landfill (R03). It means that burying the solid waste has generated this metal in the soil, reflecting the improper management of the landfilling processes. The Zn concentration in the leachate and landfills can be derived from battery waste, pigments, galvanized steel, and iron. At the Kieu Ky landfill in Hanoi, the

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Zn concentration increased when the monitoring distance was closer to the landfill, ranging from 94 to145 mg/kg at points far away from landfill, and 103–259 mg/kg at points close to the landfill (Ha 2018). At open-dumping landfills burying domestic solid waste, soil samples collected in the landfill area (52.48 ± 34.59 to 77.46 ± 57.88 mg/kg) had higher Zn concentrations than soil samples collected from 60 m away (and 4.39 ± 2.68 to 4.79 ± 0.56 mg/kg) (Vongdala et al. 2019). In this study, the Zn concentration in the soil at the landfills is still within the allowable limit of QCVN 03-MT:2015/BTNMT.

From Figure 3C, the Pb concentration in the R01 area ranged from 6.89 to 34.45 mg/kg, and was from 8.85 to 28.35 mg/kg in site R02. The Pb concentrations at R03, R04, and R05 varied from 19.66 to 42.32 mg/kg, 13.70 to 18.19 mg/kg, 14.32 to 28.82 mg/kg, respectively. Similar to the Cu and Zn concentrations, the Pb concentration at the Nui Sap town landfill (R03) was also recorded as the highest one among the five surveyed landfills (Table 6). The lead (Pb) accumulated in the soil from burying waste originated from batteries, rust, scrap iron, items made from PVC, etc. A former study also reported that the Pb concentration in the topsoil (5 cm) at a closed landfill ranged from 2.7 to 148 mg/kg (Agamuthu & Fauziah 2010). The concentration of Pb in the topsoil at the Dong Thang landfill was relatively lower than that of the present study area, ranging from 9.7 ± 0.08 to 14.6 ± 0.03 mg per kg (Giao 2020). The Pb concentration is still within the allowable limit of QCVN 03-MT:2015/BTNMT.

From Figure 3D, the As concentration at R01 ranged from 3.92 to 7.08 mg/kg. In the R02 area, the As concentrations fluctuated in the range of 8.30–14.56 mg/kg. The monitoring sites R03, R04, R05 had As concentrations fluctuating between 7.18–8.76 mg/kg, 10.56–14.42 mg/kg, 9.42–16.56 mg/kg, respectively. At the Kien An commune landfill, the As concentrations at the two monitoring sites, namely S66 (15.68 mg/kg) and S83 (16.56 mg/kg), exceeded the allowable limit of QCVN 03-MT:2015/BTNMT. It was the landfill with the highest As concentration among the five landfills (Table 6). At a closed landfill, the As concentrations were found to be at 8.8–64.5 mg/kg and 0.3–2.7 mg/kg in the topsoil (5 cm) and deep soil (5 m), respectively (Agamuthu & Fauziah 2010). Ha (2018) reported that the As concentration at the Kieu

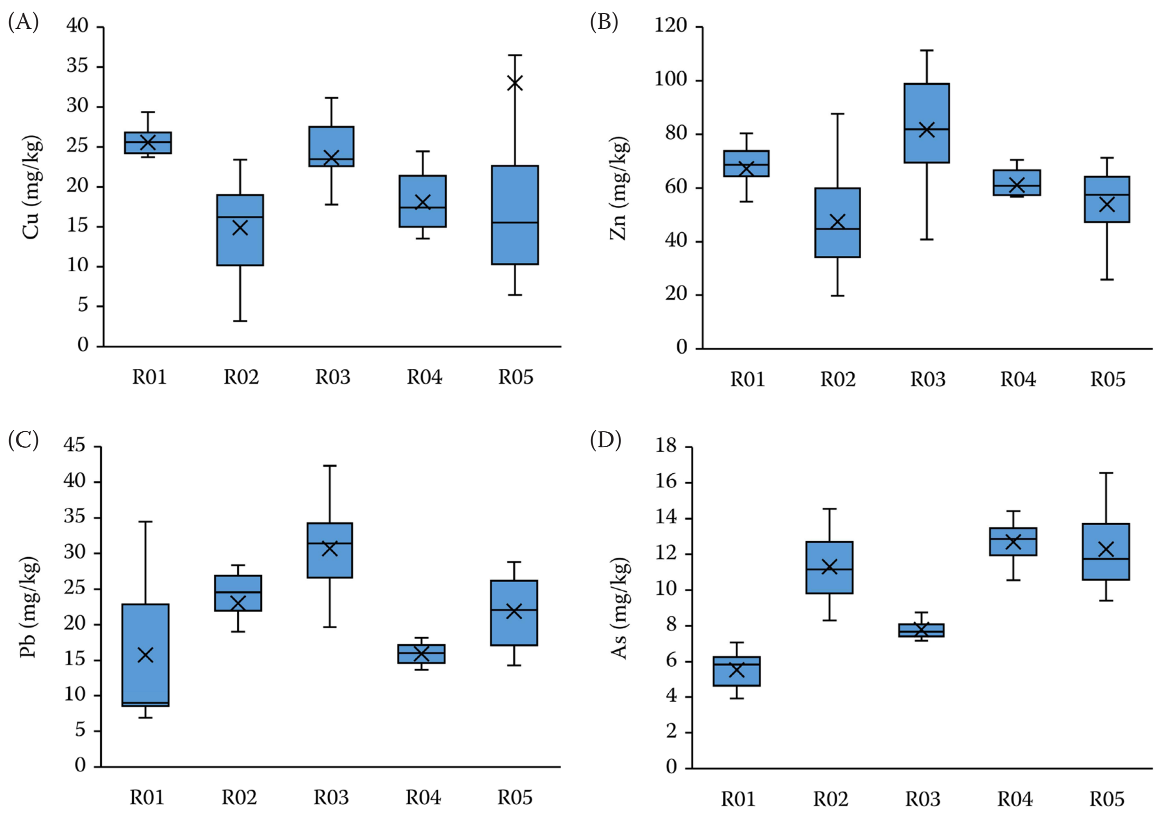

Figure 3. Concentrations of Cu (A), Zn (B), Pb (C) and As (D) in the soil surrounding the landfills

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Table 6. Average value of the potentially toxic element content of each landfill (mg/kg)

No.	Area	Cu	Zn	Pb	Cd	As
1	R01	25.56 ± 3.99	67.19 ± 12.87	15.76 ± 9.8	0	5.54 ± 0.98
2	R02	14.91 ± 5.97	47.54 ± 17.16	23.03 ± 5.22	0	11.31 ± 1.85
3	R03	23.68 ± 4.61	81.76 ± 18.90	30.7 ± 6.15	0	7.79 ± 0.45
4	R04	18.10 ± 3.76	61.20 ± 7.42	15.94 ± 1.50	0	12.70 ± 1.23
5	R05	33.02 ± 49.31	53.99 ± 12.67	21.9 ± 4.83	0	12.29 ± 1.89

Table 7. Potentially toxic element concentrations (mg/kg) by the clusters

Toxic elements	Cluster								QCVN 03-MT:2015/BTNMT[1]
	1	2	3	4	5	6	7	8	
Cu	155.87	3.17	28.11	26.25	24.31	17.22	19.92	9.83	100
Zn	50.73	19.76	38.32	71.54	80.51	61.87	41.18	40.08	200
Pb	21.81	14.07	8.53	8.43	29.07	17.96	26.38	25.12	70
As	11.40	13.70	4.98	5.22	7.26	12.29	8.21	12.69	15

[1]National technical regulation on the allowable limits of heavy metals in soils

Ky landfill was in the range of 16–33 mg/kg exceeding the allowable limit of QCVN 03-MT:2015/BTNMT.

Cd is not detected in the landfill soils. Former studies also reported that the Cd concentration is insignificant in landfills (Kamani & Gandhimathi 2013; Pongpom et al. 2014; Tautua et al. 2014). Although Cd was not detected in this study area, other potentially toxic elements (Cu, Zn, Pb, and As) occurred at the dumps, especially in the unsanitary and open-dump landfills.

Spatial distribution of the potentially toxic element concentrations in the landfills. The results of the cluster analysis showed that there were eight soil quality groups from 88 topsoil samples Figure 4). Group I, which included three topsoil samples (S67, S71, S86), was different from the rest, mainly through its high Cu concentration that exceeded the permissible limit (Table 7). These three topsoil samples were all collected around the Kien An landfill. Groups 2 (S27) and 3 (S3) had samples with different toxic element concentrations in the soil, which were almost all lower than the other groups (Table 7). Group 4 included eleven topsoil samples (S1, S4, S5, S7, S8, S9, S10, S12, S13, S15, and S16) which were the sam-

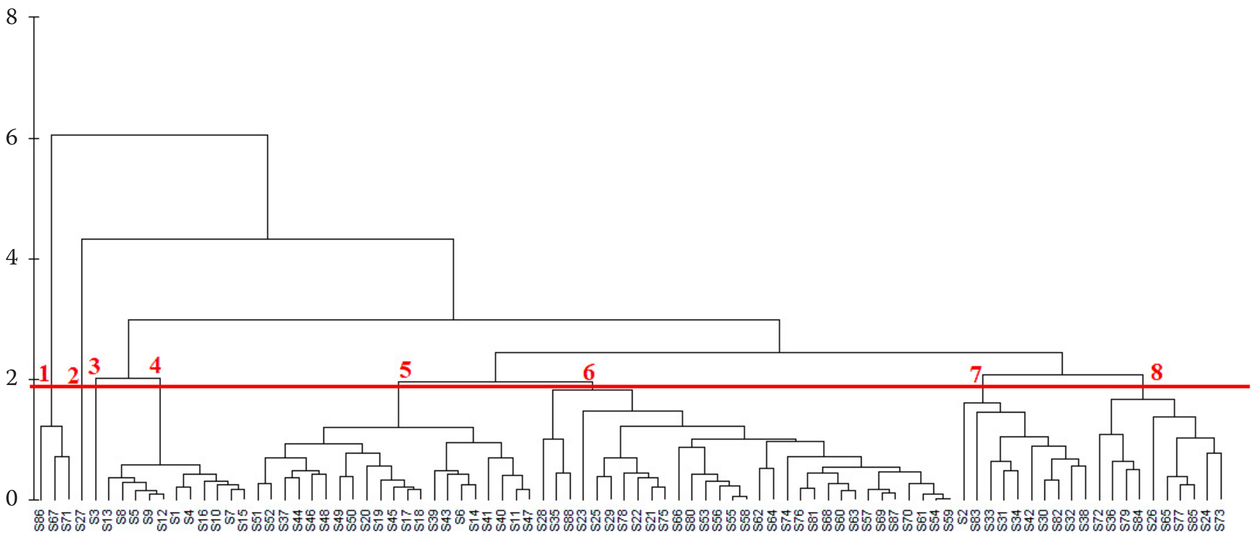

Figure 4. Clustering results of the potentially toxic element content at each monitoring location

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Table 8. Potential ecological risk index for each potentially toxic element

Parameter	R01	R02	R03	R04	R05
Cu	6.46	3.77	5.99	4.58	8.35
Zn	1.42	1.01	1.73	1.30	1.14
Pb	5.25	7.68	10.23	5.31	7.30
Cd	0.00	0.00	0.00	0.00	0.00
As	29.16	59.53	41.00	66.84	64.68

Table 9. Composite potential ecological risk index for each landfill

Code	Landfills	RI	Risk
R01	solid waste treatment complex in Long Xuyen cluster	42.30	low
R02	solid waste treatment area Kenh 10	71.98	low
R03	landfill at Nui Sap	58.95	low
R04	landfill at My Luong	78.03	low
R05	landfill at Kien An	81.48	low

RI – potential ecological risk index

pling points in the solid waste treatment complex of the Long Xuyen cluster. The Pb and As concentrations were lower than those in the other survey sites (Table 7). However, Group 4 had both locations on the premises and places around the landfill. Group 5 had 21 topsoil samples that includes: seven topsoil samples at the solid waste treatment complex of the Long Xuyen cluster (S6, S11, S14, S17, S18, S19, S20) and fourteen topsoil samples at the landfill in Nui Sap (S37, S39, S40, S41, S43, S44, S45, S46, S47, S48, S49, S50, S51, S52). The above results suggest choosing two topsoil samples in the Long Xuyen cluster complex treatment site and one topsoil sample in the Nui Sap landfill to monitor toxic element concentrations in the future. Group 6 included 31 topsoil samples belonging to three landfills, such as the Kenh 10 solid treatment area (S21, S22, S23, S25, S28, S29, S35), My Luong landfill (S53, S54, S55, S56, S57, S58, S59, S60, S61, S62, S63, and S64) and Kien An commune landfill (S66, S68, S69, S70, S74, S75, S76, S78, S80, S81, S87, S88). In Group 3, each landfill selected two sampling sites to collect soil samples. Similarly, the number of soil sampling locations in Groups 7 and 8 can be reduced from ten to four topsoil samples and ten to three topsoil samples, respectively.

According to the results of the CA, the total current sampling locations at the five landfills can be significantly reduced. For example, the Kenh 10 site, the solid waste treatment complex of the Long Xuyen cluster, can be decreased to six topsoil samples. Similarly, the Nui Sap landfill, My Luong town landfill, and Kien An landfill only two, two, and seven topsoil samples can be collected, respectively. It still ensures a representativeness and the accuracy of the monitoring. Thus, the budget and time for the monitoring can be greatly reduced in the future research.

Assessment of the potential ecological risks. The risk factor of each potentially toxic element and the combined ecological possible risk factor at each landfill were calculated. In Table 8, the Cu risk factor (E_r^p) in five landfills ranged from 3.77 to 8.35; the Zn risk factor ranged from 1.01 to 1.73; the Pb risk factor fluctuated between 5.25 and 10.23; the As risk factor varied from 29.16 to 66.84. There is no risk effect with Cd. For the landfills R01 and R05, the order of the risk factors was As > Cu > Pb > Zn > Cd. For the remaining three sites, the order of the risk factors was As > Pb > Cu > Zn > Cd. Overall, As was one of the major environmental risk factors among the five risky elements studied. The risk rating scale showed that the over ecological potential risk index of five potentially toxic elements at five landfills was R05 > R04 > R02 > R03 > R01 (Table 9). The risk level of the Kien An landfill and My Luong landfill was higher than that in the remaining landfills even though the overall potential ecological risk is low.

CONCLUSION

The concentrations of the potentially toxic elements (Cu, Zn, Pb, and As) in the soil were within the allowable limits of QCVN 03-MT:2015/BTNMT. The Cd concentration was under the detection limit in the soil samples. The potentially toxic element concentrations were high in the open-dumping landfills. The cluster analysis divided all the current monitoring sites into eight clusters and it allows one to decrease the budget of the monitoring in any future research. The potential ecological risk calculation showed the risk rating scale of the five landfills was in the order of R05 > R04 > R02 > R03 > R01. Although the overall potential ecological risk is low, the Kien An and My Luong landfills were at a higher risk than the others. Monitoring these toxic elements at the landfill should be continued because the long-term accumulation of toxic elements in the soils could have unpredictable consequences for the ecosystem and human health.

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