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Ecological Risk Assessment for Occurrence of Toxic Elements in Various Land Use Types in Vietnamese Mekong Delta Province

Huynh Thi Hong Nhien[1], Le Thi Diem Mi[1], Nguyen Thanh Giao[1*]

[1] College of Environment and Natural Resources, Can Tho University, Campus II, 3/2 Street, Xuan Khanh ward, Ninh Kieu district, Can Tho City 900000, Vietnam

* Corresponding author's e-mail: ntgiao@ctu.edu.vn

ABSTRACT

A total of 316 soil samples in the An Giang province were collected from the industrial zone (48 samples), mining (40 samples), farming (112 samples), landfills (88 samples) and cemeteries (28 a samples) to analyze toxic elements, including Cu, Zn, Pb, Cd and As. The geoaccumulation index (I_{geo}), pollutant load index (PLI) and potential ecological risk index (RI) were used to assess pollution levels and ecological risks. The results showed that the concentrations of heavy metals were almost still within the allowable limits of national standards. Cd was not detected. Heavy metals were detected in the soil in the following order: As < Pb < Cu < Zn, mining < industrial < landfill < cultivation < cemetery areas. The heavy metals contributing to soil environmental variability were similarly identified in the cemetery with industry and landfill with farming. The value of I_{geo} shows that As has a high potential to accumulate in soil in all land uses. The ranges of PLI values presented that the soil in industrial, farming, mining and landfills areas were classified moderate, while the cemetery areas has been rated at a high level. The RI values identified very high, high, and moderate ecological risks for cemetery, industrial and farming land and landfill, mining, respectively. The combination of PLI and RI indices showed that the cemetery areas were at the highest levels of pollution and risk. The results of this study provide scientific information on pollution level and ecological risks in various land use types supporting environmental zoning and managing strategies in the An Giang province.

Keywords: An Giang, ecological risks, heavy metals, land-use types, pollution index.

INTRODUCTION

An Giang is the largest rice cultivation area in the Vietnamese Mekong Delta. In particular, An Giang is known as the seven mountains with strong development of mining and stone processing as construction materials [Quang and Trang 2018]. Several studies showed that agricultural soil has signs of heavy metal pollution [Hung and Thom 2016, Ha, 2018]. The concentration of heavy metals occurring in the soil depends on the sources and the amounts of emissions [Trinh et al. 2018]. Agricultural activities contribute heavy metals to the soil environment, mainly through the use of chemical fertilizers, pesticides and contaminated irrigation water [Wei and Yang 2010, Huang et al. 2019, Guan et al. 2019]. Various industrial activities contribute heavy metals to the soil environment directly or indirectly through solid waste, air emissions and wastewater [Solgi et al. 2012]. The occurrence of heavy metals in soil could lead to soil degradation. Currently, the area of soil degradation in the An Giang province is about 96,745 ha, of which the heavily degraded land area is 12,558 ha, the average degradation is 74,113 ha and mild degradation is 10,074 ha. These areas are concentrated mainly in the districts of Tri Ton, Tinh Bien, Chau Phu, Thoai Son and Chau Thanh. It can be seen that social-economic development would demand for exploitation and use of natural resources that would lead to the generation of several types of wastes, resulting in the deterioration of the environmental quality. The heavy metals derived from social-economic activities can persist for centuries in soil, possibly further transferring to groundwater, animals and plants [Khalid et al. 2017]. This would pose a long-term threat to human health, plant growth and the ecosystem as a whole [Sun 2017]. Up to present, the information on heavy metal pollution and risk associated with toxic elements has been limited. This study aimed at assessing of the pollution level and risks related to heavy metals in various soil types in the An Giang province. The results could provide scientific basis for proposing the measures to manage the heavy metal pollution from socio-economic development activities in the province.

MATERIALS AND METHODS

Description of study area

An Giang is a border province in the Mekong Delta with a natural land area of 353,668 ha, accounting for 8.73% of the whole area. The An Giang province has with two topographic forms including plains and hills, accounting for about 87% and 13% of the natural land area in the province, respectively. In general, the terrain is less complicated, relatively favorable for the development of agriculture – forestry – fishery, tourism and industry. In terms of agriculture, the total area of annual crops is about 680.1 ha in 2019, of which the area of vegetables and rice accounts for about 54.7 thousand hectares and 625.4 thousand ha, respectively. The pesticides used annually for rice are about 11.5 kg/ha/year and vegetables are 6.1 kg/ha/year. In the industrial sector, the industrial production value in 2019 relatively increased, reaching 32,036.4 billion VND, of which the mining industry reached 251 billion VND, the processing industry reached 30,524 billion VND, water supply and wastewater treatment industry reached 460 billion VND. Only in 2018, the land area of production and business establishments increased to 1,553.74 ha. There are three industrial parks operating in the province, including two large industrial parks. The first is Binh Hoa Industrial Park, Chau Thanh District, with an area of 131.78 ha, that produces building materials, garments, steel casting, and pharmaceuticals. The other park, i.e. Binh Long Industrial Park, Chau Phu District, with an area of 28.56 hectares has the main production industries of seafood processing, aqua feed and fishmeal. In addition, the province currently has nine industrial clusters, 29 handicraft villages and many other production and business establishments. Moreover, mining activities are also highly developed; the province has discovered 78 mineral mines and has two licensed quarries, namely Nui Dai and Co To. Regarding solid waste treatment, there are 36 landfills in the province, of which three are considered hygienic in three concentrated waste treatment zones, while 33 open dumpsites cause serious environmental pollution. The areas of cemeteries have been formed for a long time, without a drainage system, and without proper planning, which can affect the quality of the environment. This study aimed at evaluating the ecological risk associated with occurrence of toxic elements in the just mentioned land use types.

Soil sampling and analysis

For this study, the soil sampling locations were distributed in the areas and sources that can cause heavy metal pollution in soil in the An Giang province, including industrial areas (industrial parks, clusters, craft villages, seafood processing), mining areas, farming areas, waste dumps and cemetery areas. The study collected a total of 316 soil samples in the topsoil layer, with a depth of no more than 30 cm. For the soil samples in the concentrated industrial activity area in six districts, cities and towns, 48 sampling sites (I1–I7) were established, including Chau Thanh, Chau Phu, Thoai Son, Long Xuyen, Tan Chau and Phu Tan districts. For the mining areas, the collection of 40 soil samples (M1–M4) was carried out in three districts and cities, including Tri Ton, Cho Moi and Long Xuyen. A total of 112 soil samples in farming areas (F1–F7) were conducted in five districts and cities including An Phu, Cho Moi, Phu Tan, Long Xuyen and Tri Ton. Soil samples from the landfill areas were collected in four districts and cities, including Chau Thanh, Chau Doc, Thoai Son and Cho Moi with 88 sampling sites (L1–L5). Finally, 28 soil samples from the cemetery areas were sampled in Long Xuyen city (C1–C2). The study assessed risk through five toxic elements including copper (Cu), zinc (Zn), lead (Pb), cadmium (Cd) and arsenic (As). Sampling time was from January 2020, with the methods of sampling and preserving samples according to the standards specified in Ministry of Science and Technology (2005). Toxic elements such as Cu, Zn, Pb, Cd were analyzed according to the standards specified in Minitry of Science and Technology (2009).

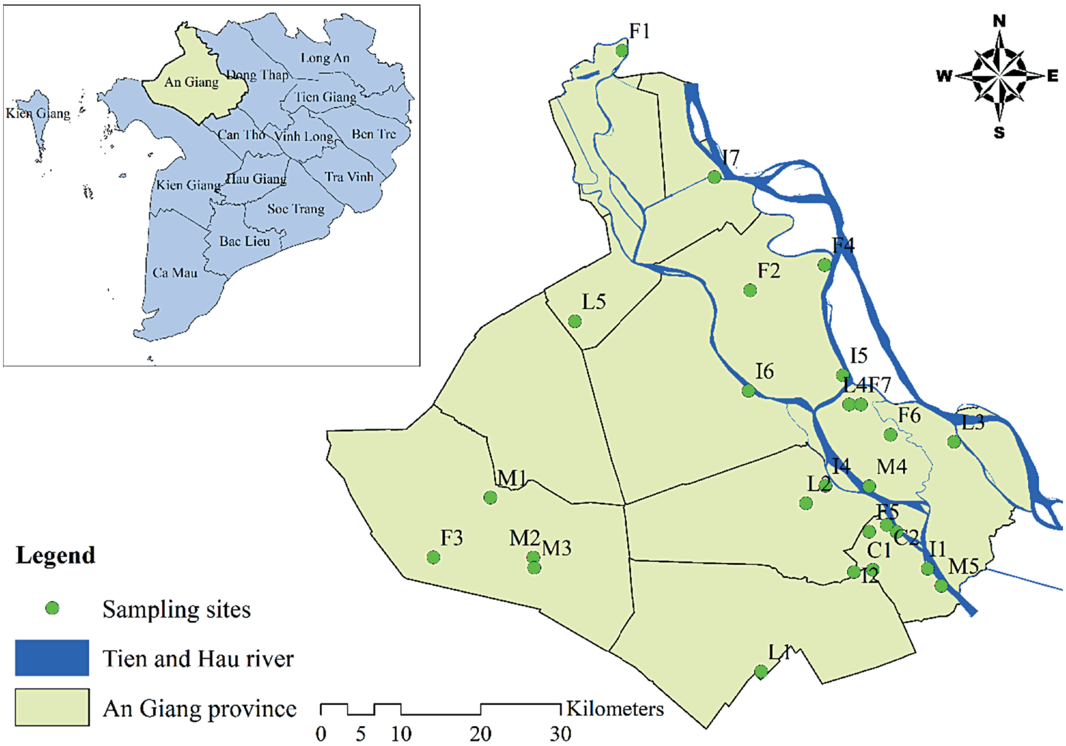

Figure 1. Map of soil sampling locations in the study area

Data analysis

The data of heavy metals in the soil were aggregated according to each type of land use in the An Giang province using the Excel software. The data was analyzed to determine Mean, SD, Min, Max values and presented as a Boxplot chart using IBM SPSS Statistics 20.0 software. Besides, One-way ANOVA statistical analysis was applied to evaluate the statistically significant difference between the sampling areas. The results showed that the difference was statistically significant when $p < 0.05$. The heavy metal content in the soil in the study areas was compared with the national technical regulation on the allowable limits of heavy metals in the soils (QCVN 03-MT:2015/BTNMT) [Ministry of Natural Resources and Environment, 2015] corresponding to each type of land use as indicated in Table 1. Pearson correlation and Principal Component Analysis (PCA) were based on heavy metal data at each site of each land use type. The analysis aimed to determine the degree of positive or negative correlation between heavy metals, as well as determination of the origin of heavy metals formation in soil at different land use types [Hu et al. 2013, Islam et al. 2019]. Pearson analysis was performed using the IBM SPSS Statistics 20.0 software and PCA analysis was performed using the Primer 5.2 Windows software (Primer-E Ltd, Plymouth, UK).

To quantify pollution and potential risk to a contaminated area, the Nemerov Pollution Index (PI_N), the Geographic Cumulative Index (I_{geo}), the Pollution Load Index (PLI) and the Risk Index (RI) potential ecology were applied in this study. The Single Pollution Index (PI) was used to assess the pollution level of each heavy metal in the topsoil determined by the equation 1 [Kowalska et al. 2018]:

$$PI = \frac{C_n}{G_b} \tag{1}$$

Table 1. Maximum allowable limits of heavy metal contents in various soil types

No.	Parameters	Units	Industrial soil	Agricultural soil	Residential area
1	Cu	mg/kg	300	100	100
2	Zn	mg/kg	300	200	200
3	Pb	mg/kg	300	70	70
4	As	mg/kg	25	15	15

Geoaccumulation Index (I_{geo}) was applied to evaluate the accumulation level of each heavy metal in the soil using equation 3 [Kowalska et al. 2018]:

$$I_{geo} = \log_2 \frac{C_n}{1.5 \times G_b} \quad (2)$$

Pollution Load Index (PLI) was calculated to indicate the pollution level of heavy metals according to equation 4 [Kowalska et al. 2018]:

$$PLI = \sqrt[n]{PI_1 \times PI_2 \times PI_3 \times \cdots \times PI_n} \quad (3)$$

Potential ecological risk (RI) was used to assess the potential risk, the combined toxicity of heavy metals to the ecological system. The index was calculated using the equation 5 [Hakanson 1980, Ramdani et al. 2018]:

$$RI = \sum_{i=1}^{n} E_r^i = \sum_{i=1}^{n} T_r^i \times PI \quad (4)$$

In which, C_n is the heavy metal content in analyzed soil samples; G_b is the value of the geochemical background corresponding to As, Pb, Cu, Zn and Cd are 0.67, 27, 38.9, 70 and 0.41, respectively [Kabata-Pendias 2001, Kowalska et al. 2018]; Pimax is maximum value of single pollution index (PI); PI is value of single pollution index; n is the number of heavy metals; E^i_r is potential ecological risk factor for each metal; T^i_r is the toxicity coefficient of metal corresponds to As, Pb, Cu, Zn and Cd are 10, 5, 5, 1 and 30, respectively [Hakanson 1980] (Table 2).

RESULTS AND DISCUSSION

Concentration of heavy metals in soil in different types of land uses

The heavy metal content in the soil of the An Giang province in different land use areas was presented in Figure 2. Heavy metals occurred in soil in different land use types in increasing order of As < Pb < Cu < Zn. Cd was not detected in any soil sample. The Cu concentration ranged from 19.78±12.65–34.29±20.1 mg/kg (Figure 2a). The average concentration of Cu was highest in the industrial area and the lowest in the rice cultivation area. One-way ANOVA analysis showed a statistically significant difference between the industrial, mining areas and rice cultivation ($p < 0.05$). This trend has significantly reflected the impact through the deposition of dust and waste from industrial activities. The Zn content varied from 47.16±22.39–83.22±23.35 mg/kg (Figure 2b). The study did not find a significant difference between industrial land and cemetery soil ($p > 0.05$); however, both of these land use types showed significant differences with cultivation and mining land ($p < 0.05$). The highest concentrations of Zn were found in the soil at the cemetery. This was also reported in the recent study by Mordhorst et al. (2022), because Zn is a natural component of wood and may have been introduced into the soil. Besides, the Zn concentration was also recorded high in industrial soil and was not significantly different from soil in cemetery area ($p < 0.05$). Previous studies have also reported that Zn is high in the soil around factories and roads [Ma et al. 2016, Wu et al. 2021]. In addition, Figure 2b shows a relatively large standard deviation of Zn,

Table 2. Pollution and risk rating scale [Kowalska et al. 2018, Thongyuan et al. 2020]

Index	Values	Rating	Index	Values	Rating
RI	RI < 50	Low	PLI	PLI ≤ 1	No pollution
	50 ≤ RI < 100	Moderate		1 < PLI ≤ 2	Moderate
	100 ≤ RI < 200	High		2 < PLI ≤ 3	High
	RI ≥ 200	Very high		PLI >3	Extremely high
PI_N	$PI_N \leq 0.7$	Safe level	I_{geo}	$I_{geo} \leq 0$	No pollution
	$0.7 < PI_N \leq 1$	Need warning		$0 < I_{geo} < 1$	No to moderate
	$1 < PI_N \leq 2$	Mild pollution		$1 < I_{geo} < 2$	Moderate
	$2 < PI_N \leq 3$	Moderate		$2 < I_{geo} < 3$	Moderate to high
	$PI_N > 3$	Heavy pollution		$3 < I_{geo} < 4$	High
				$4 < I_{geo} < 5$	High to very high
				$5 < I_{geo}$	Extreme pollution

which showed that the dispersion degree for Zn was very large and a high interference of anthropogenic activities [Jiang et al. 2019].

The Pb concentration for land-use types was 15.69±7.64 mg/kg (industrial area), 17.42±17.42 mg/kg (mining area), 30.25±3.95 mg/kg (cemetery area), 21.5±8.15 mg/kg (landfill area), 22.67±7.61 mg/kg (cultivation area), respectively. The Pb concentration was also detected in the cemetery soil and was different from the rest of the areas ($p < 0.05$). The distribution of As showed a relatively high concentration in land-use types similar to Pb; the As concentrations ranged from 5.09±5.09 to 15.24±2.03 mg/kg (Figure 2d). It can be seen that the As in the soil fluctuates to a relatively large extent in the study area. The mean concentration of As in cemetery soil was found to be significantly higher than that of other land uses ($p < 0.05$). In the cemetery areas, As was found to exceed the permissible limit from 1.03–1.25 times. The emissions and wastes from brick making as well as incineration activities also contribute to the increase of the As concentration in the soil [Olawoyin et al. 2012]. Burial operations, leaching from the cemetery, and wood preservatives used to make coffins are considered sources of As formation in the soil [Sponberg & Becks 2000, Amuno 2013]. Besides that, the high levels of As in the soil can be attributed to the use of fertilizers and pesticides in the agricultural sector [Islam et al. 2019, Fan et al. 2019]. In general, the heavy metal contents in different types of land use have significantly fluctuated. The concentrations of heavy metals in the soil at all land use types were mostly in accordance with the allowable limits of national standard, except a few sampling sites with Cu and As exceeding the specified thresholds. It is worth noting that the heavy metals were highly accumulated in the cemeteries soil compared with the other types of land use. The concentrations of heavy metals (except Cu) from different land uses were shown in the following descending order: cemetery > cultivation > landfill > industrial > mining. These findings show a clear correlation of land use with soil heavy metal concentrations.

Correlation of heavy metals in various land use types

The Pearson correlation coefficient determining the relationship between soil heavy metals at different land uses was shown in Table 3.

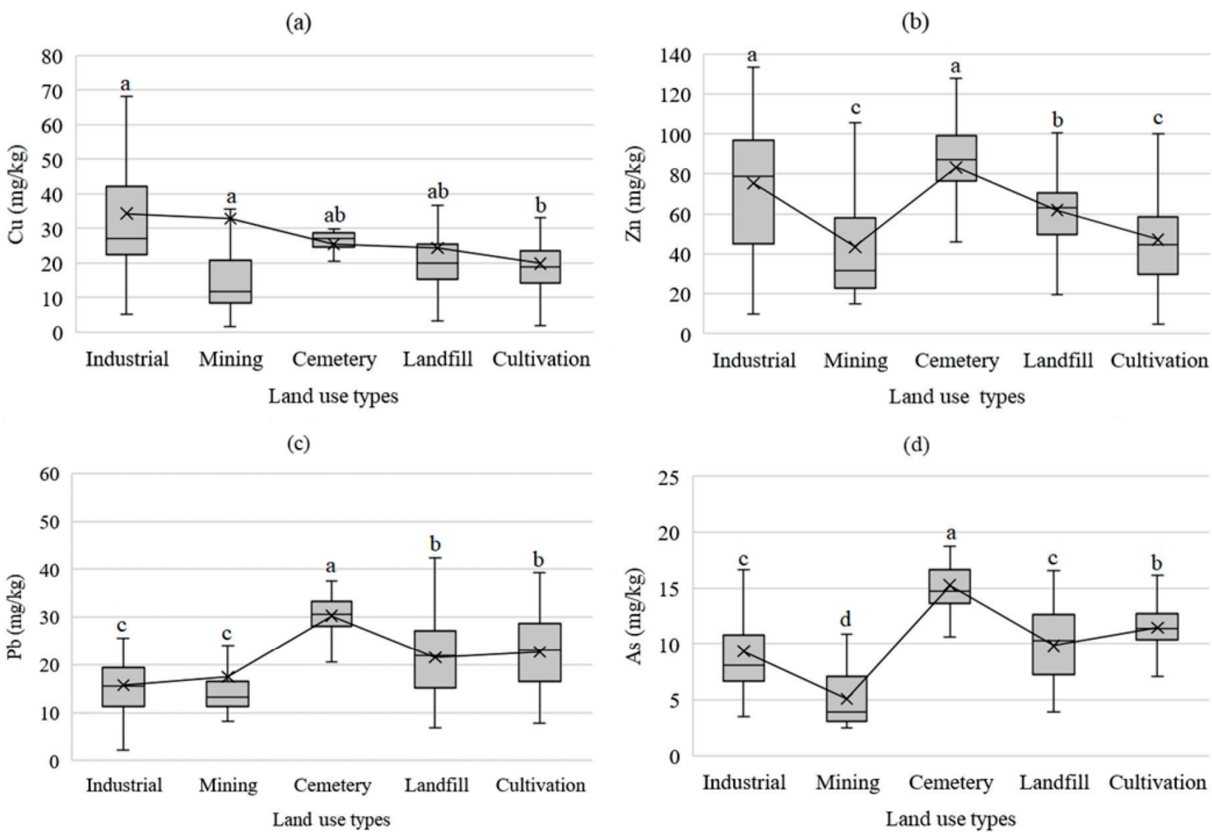

Figure 2. Heavy metals content (Cu, Zn, Pb and As) in land use types

Table 3. Results of heavy metal correlation in soil

Land use types	Parameter	Cu	Zn	Pb
Industrial	Zn	0.532**	-	-
	Pb	0.675**	0.710**	-
	As	-0.092	0.112	0.084
Mining	Zn	0.456**	-	-
	Pb	0.571**	0.812**	-
	As	0.503**	0.772**	0.696**
Cultivation	Zn	0.127	-	-
	Pb	-0.163	0.303**	-
	As	0.083	0.06	0.035
Landfill	Zn	0.056	-	-
	Pb	-0.007	0.099	-
	As	-0.05	-0.356**	0.02
Cemetery	Zn	0.722**	-	-
	Pb	0.486**	0.237	-
	As	-0.03	-0.228	-0.085

** – Correlation is significant at the level of 0.01.

The correlation may indicate that the heavy metals formed in the soil are of similar or different origin [Hu et al. 2013, Chabukdhara et al. 2016]. The correlations of heavy metals were recorded in the following order: (1) mining area, (2) industrial area, (3) cemetery area, (4) farming area and landfill. For the industrial areas, Cu, Zn, Pb were closely mutually correlated at the significance level of 1% ($p < 0.01$) in which the correlation coefficients between Cu and Pb, Cu and Zn, Zn and Pb were 0.532, 0.675 and 0.719, respectively. This showed that Cu, Pb and Zn may have the same origin, and the same influencing factors [Long et al. 2021]. Besides, this correlation has also been recorded previously in the area affected by industrial activities [Krishna and Mohan, 2016]. As was almost uncorrelated with any metal in the soil, indicating that the sources contributing to the accumulation of As were different from other heavy metals. Similar to the soil in the industrial area, high positive correlations were identified in the soil in the cemetery area. Specifically, the correlation coefficients between Cu and Zn, Cu and Pb were 0.722 and 0.486 ($p < 0.01$), respectively. In the mining areas, all heavy metals were highly correlated ($p < 0.01$), which implied that the metals were of a common origin. Meanwhile, the correlation of Zn and Pb was only recorded in the soil of the cultivation area, the correlation coefficient was 0.303 ($p < 0.01$). At the same time, the study also found a weak correlation of Zn and As in the soil of the landfill area.

In addition, the study also analyzed PCA to clarify the relationship and origin of heavy metals in soil [Zhang et al. 2009]. On the basis of the eigenvalue > 1 [Hu et al. 2013, Long et al. 2021], two main components were extracted at each land use type (Table 4). The PCA analysis of industrial, mineral, farming, landfill and cemeteries explained 83.1%, 88.4%, 61.7%, 60% and 75.7% of the variability of the original data set, respectively. In the industrial area, the PCA results showed that PC1 aggregated Cu, Zn and Pb positively correlated with each other and PC2 strongly correlated with As (0.965), which could indicate common contamination source for these metals. The separate contribution of As compared with Cu, Zn, Pb in industrial soils has been reported in the study of [Krishna and Mohan, 2016]. The very high contribution of As can be predicted by the discharge of industrial waste and sludge from factories in the study area; This may contribute to the As contamination in the soil [Bo et al. 2022]. For the mining areas, Zn, Pb, and As contribute to the PC1 source, accounting for 73.1%. However, PCA also showed that Cu was still another source of waste formed when PC2 was strongly correlated with Cu (0.890). The cultivation area, the analysis results showed that Zn and Pb were contributed to soil environmental variability (PC1).

Table 4. Principal component analysis of heavy metal parameters in soil

Land use	Industrial		Mining		Cultivation		Landfill		Cemetery	
	PC1	PC2	PC1	PC2	PC1	PC2	PC1	PC2	PC1	PC2
Cu	**0.552**	-0.236	-0.417	**0.890**	-0.027	**-0.798**	-0.188	**0.449**	**-0.673**	-0.222
Zn	**0.569**	0.111	**-0.529**	-0.376	**0.690**	-0.220	**-0.699**	-0.102	**-0.594**	0.116
Pb	**0.608**	0.031	**-0.532**	-0.093	**0.695**	0.319	-0.145	**-0.872**	**-0.454**	-0.231
As	0.050	**0.965**	**-0.513**	-0.240	0.200	**0.462**	**0.647**	-0.167	0.188	**-0.940**
Eigenvalues	2.28	2.04	2.93	0.61	1.32	1.15	1.38	1.02	2.03	1
%Variation	57.1	26	73.1	15.3	32.9	28.7	34.5	25.5	50.7	25
Cum. %Variation	57.1	83.1	73.1	88.4	32.9	61.7	34.5	60	50.7	75.7

PC2 had a strong negative correlation with Cu (-0.798) and weakly correlated with As (0.462). In the landfill area, PC1 was formed by Zn and As (accounted for 34.5%), consistent with the correlation analysis. PC2 showed a weak correlation with Cu (0.449) and closely with Pb (-0.872). Finally, the heavy metals (Cu, Zn, Pb) in cemetery area were considered to have the same origin, which contributed to PC1. PC2 was highly negatively correlated with As (-0.940).

From the results of correlation analysis and PCA, it can be seen that the impact of activities on the ground significantly affects the characteristics of the soil environment in the study area [Jonker & Olivier 2012, Ajah et al. 2015, Chabukdhara et al. 2016, Klinsawathom et al. 2017]. Specifically, industrial areas and cemeteries have similar characteristics of soil environmental changes; meanwhile, the heavy metals in the cultivation and landfill areas have similar variation.

Pollution and risk at various land use types in the study areas

The geological accumulation indices (I_{geo}) of four heavy metals in soil by different land use types were presented in Table 5. For industrial areas, the average I_{geo} values of Cu, Zn, Pb and As were -0.98, -0.65, -1.59 and 3.09, respectively. The I_{geo} values showed that the soil in the industrial area is likely to accumulate Cu and Zn at none to moderate levels, Pb (unpolluted), and As (moderately to highly polluted). For the mining area, the average I_{geo} values of Cu, Zn, Pb and As were -2.24, -1.54, -1.43 and 2.18, respectively. Cu exhibited a state from no-pollution to high-contamination, Zn and Pb in a non-polluted state, and As from moderately to highly polluted state. For the cultivated area, the I_{geo} values indicated that the accumulation potential was assessed at none to moderate for Cu and Zn, Pb was at unpolluted level, while As was determined at moderately to extremely polluted levels. For the landfill and cemetery areas, Cu, Zn and Pb were from non-polluted to moderately polluted and As was from moderate to extremely high pollution. Through the above analysis, it was shown that As was the heavy metal with the highest ability to accumulate in soil in all different types of land use. The mean I_{geo} values gradually increased from Cu < Pb < Zn < As in most land use types. In industrial areas, the average value of I_{geo} increased from Pb < Cu < Zn < As. In the farming area, the mean I_{geo} increased from Cu < Zn < Pb < As (Table 5).

The pollution load index (PLI) of heavy metals in soil according to different land-use types in the An Giang province was shown in Figure 3. Figure 3 shows that the highest levels of heavy metal contamination were recorded in the cemetery area; followed by landfill and industrial areas; the final was cultivation and mining areas. The mean PLI value indicated that the heavy metal pollution risk was assessed as high for the cemetery area, and moderate for the rest of the areas.

The values of PLI in industrial area ranged from 0.43 to 2.96, showing that the level of heavy metal contamination in the soil from unpolluted to highly polluted with 16.67% of unpolluted soil samples, 60.41% of moderate contaminated soil samples and 22.92% of highly contaminated soil samples. For the soil in the mining area, the PLI values ranged from 0.42 to 4.01, which consisted of 70%, 17.50%, 5% and 7.50% of the soil samples with unpolluted, moderately polluted, highly polluted and extremely polluted, respectively. The soil of the cultivated area had the pollution levels as non-polluted, moderate and highly

Table 5. Calculated I_{geo} values

Land use types	I_{geo}	Cu	Zn	Pb	As
Industrial	Ranges	(-3.53)–(0.46)	(-3.40)–(0.35)	(-4.17)–0	1.79–4.22
	Mean	-0.98	-0.65	-1.59	3.09
Mining	Ranges	(-5.11)–(2.56)	(-2.81)–(0.6)	(-2.31)–(0.9)	1.31–3.44
	Mean	-2.24	-1.54	-1.43	2.18
Cultivation	Ranges	(-4.99)–(1.09)	(-4.43)–(0.12)	(-2.36)–(-0.05)	2.21–4.02
	Mean	-1.75	-0.132	-0.93	3.48
Landfill	Ranges	(-4.20)–(1.64)	(-2.41)–(0.08)	(-2.56)–(0.06)	1.96–4.04
	Mean	-1.58	-0.83	-1.04	3.2
Cemetery	Ranges	(-2.82)–(-0.97)	(-1.92)–(0.28)	(-0.98)–(-0.11)	3.40–4.22
	Mean	-1.24	-0.41	-0.43	3.91

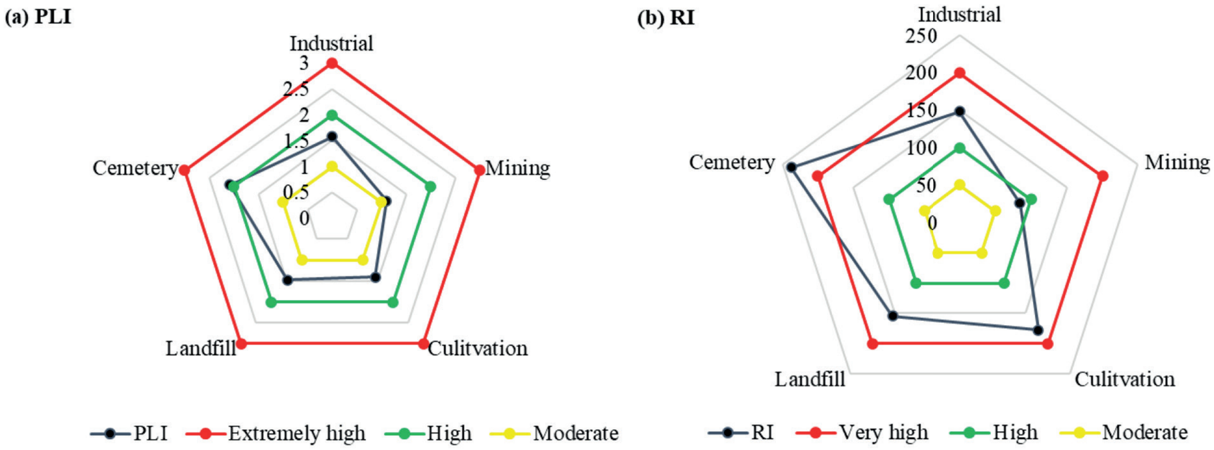

Figure 3. Values of PLI and RI at each type of land use

polluted with the PLI values ranging from 0.5 to 2.27 and soil sample rates of 4.46%, 91.97% and 3.57%, respectively. Similarly, the PLI values of soil in the landfill areas also ranged from non-polluted to highly polluted with the PLI values of 0.7–2.71. In the cemetery area, the soil was evaluated from moderate to highly polluted, which the PLI values varied from 1.14–2.33. In which, there was about 21.43% of the moderately contaminated soil samples and 78.57% of the highly polluted soil samples.

The potential ecological risk index (RI) of heavy metals in soil was shown in Figure 3. For industrial soil, the values of RI ranged from 55.15 to 282.8 with moderate to very high risk, in which moderate and very high potential ecological risks accounted for 20.83% and high risk accounted for 58.33% of the observed soil samples. The RI values in the mining areas were recorded mainly at the moderate level, with about 45% of the total soil samples and 25% of soil samples at low risk. In addition, cultivation areas and landfill area show moderate to high ecological risks. Specifically, the RI values at the cultivation and the landfill ranged from 72.08–251.46 and 63.72 to 257.93, respectively. In the cemetery areas, the RI values were relatively high from 168.11 to 288.35, representing a potential ecological risk status from high to very high (3.57% of the soil samples at high risk, 96.43% of soil samples at very high risk). Through the analysis results, the cemetery area had the highest potential ecological risk (Figure 3). The high levels of contamination and potential ecological risks from heavy metals in the cemetery area have also been reported in previous research [Mordhorst et al. 2022]. In addition, the land areas in the An Giang province, used for burial activities, cemeteries and graveyards have existed for a long time; however, there is no effective system to treat overflow water, drainage and anti-corrosion materials leading to the accumulation of heavy metals in the soil. In the farming area, the overuse of pesticides in agricultural production is the main cause for the increase and accumulation of heavy metals in the soil.

CONCLUSIONS

The concentrations of Cu, Zn, Pb and As in the soil at different land uses in the An Giang province were in accordance with the allowable limits of the national standard and Cd was not detected in any land-use type. The concentrations and presence of heavy metals in the soil were recorded as follows: As < Pb < Cu < Zn, mining < industrial < landfill < cultivation < cemetery. Heavy metals are strongly correlated in soil, the correlation of Cu and Zn was recorded in most areas. The origins of soil environmental variability were similarly identified between the cemetery and industrial, cultivation and landfill areas. The soils in the study area had moderate to high pollution level, based on the PLI index. The potential ecological risk index ranged from low to very high risk, gradually increasing from mining < landfill < industry < farming < cemetery. As has the highest accumulation potential of all land uses. The results of PLI and RI analysis both showed that cemetery soil had the highest pollution level and potential ecological risk. These findings have important implications in proposing the pollution prevention and mitigation strategies to reduce the heavy metal pollution in soil from various types of land uses.

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REFERENCES

1. Ajah K.C., Ademiluyi J., Nnaji C.C. 2015. Spatiality, seasonality and ecological risks of heavy metals in the vicinity of a degenerate municipal central dumpsite in Enugu, Nigeria. Journal of Environmental Health Science and Engineering, 13(1), 0–14.
2. Amuno S.A. 2013. Potential ecological risk of heavy metal distribution in cemetery soils. Water, Air, and Soil Pollution, 224(2).
3. Bo X., Guo J., Wan R., Jia Y., Yang Z., Lu Y., Wei M. 2022. Characteristics, correlations and health risks of PCDD/Fs and heavy metals in surface soil near municipal solid waste incineration plants in Southwest China. Environmental Pollution, 298, 118816.
4. Chabukdhara M., Munjal A., Nema A.K., Gupta S.K., Kaushal R.K. 2016. Heavy metal contamination in vegetables grown around peri-urban and urban-industrial clusters in Ghaziabad, India. Human and Ecological Risk Assessment, 22(3), 736–752.
5. Fan W., Zhou J., Zhou Y., Wang S., Du J., Chen Y., Zeng Y., Wei X. 2021. Heavy metal pollution and health risk assessment of agricultural land in the Southern Margin of Tarim Basin in Xinjiang, China. International Journal of Environmental Health Research, 31(7), 835–847.
6. Guan Q., Zhao R., Pan N., Wang F., Yang Y., Luo H. 2019. Source apportionment of heavy metals in farmland soil of Wuwei, China: Comparison of three receptor models. Journal of Cleaner Production, 237, 117792.
7. Ha H.H. 2018. Heavy metals pollution of the soil environment by landfill sites: a case of Kieu Ky landfill, Gia Lam, Hanoi. VNU Science Journal: Earth and Environmental Sciences, 34(2), 86–94.
8. Hakanson L. 1980. An ecological risk index for aquatic pollution control.a sedimentological approach. Water Research, 14(8), 975–1001.
9. Hu Y., Liu X., Bai J., Shih K., Zeng E.Y., Cheng H. 2013. Assessing heavy metal pollution in the surface soils of a region that had undergone three decades of intense industrialization and urbanization. Environmental Science and Pollution Research, 20, 6150–6159.
10. Huang Y., Wang L., Wang W., Li T., He Z., Yang X. 2019. Current status of agricultural soil pollution by heavy metals in China: A meta-analysis. Science of the Total Environment, 651, 3034–3042.
11. Hung P.Q., Thom T.T.H. 2016. Assessment of soil properties and contamination soil in Nhue river basin in Duy Tien district, Ha Nam province.Vietnam J. Agri. Sci., 14(11), 1741–1752.
12. Islam M.S., Ahmed M.K., Al-Mamun M.H., Islam S.M.A. 2019. Sources and ecological risks of heavy metals in soils under different land uses in Bangladesh. Pedosphere, 29(5), 665–675.
13. Jiang F., Ren B., Hursthouse A., Deng R., Wang Z. 2019. Distribution, source identification, and ecological-health risks of potentially toxic elements (PTEs) in soil of thallium mine area (southwestern Guizhou, China). Environ. Sci. Pollut. Res., 26, 16556–16567.
14. Jonker C., Olivier J. 2012. Mineral contamination from cemetery soils: Case study of Zandfontein Cemetery, South Africa. International Journal of Environmental Research and Public Health, 9(2), 511–520.
15. Kabata-Pendias A., Pendias H., 2001. Trace Metals in Soils and Plants, 2nd ed. CRC Press, Boca Raton, Fla, USA.
16. Khalid S., Shahid M., Niazi N.K., Murtaza B., Bibi I., Dumat C. 2017. A comparison of technologies for remediation of heavy metal contaminated soils. Journal of Geochemical Exploration, 182, 247–268.
17. Klinsawathom T., Songsakunrungrueng B., Pattanamahakul P. 2017. Heavy metal concentration and risk assessment of soil and rice in and around an open dumpsite in Thailand. EnvironmentAsia, 10(2), 53–64.
18. Kowalska J.B., Mazurek R., Gąsiorek M., Zaleski T. 2018. Pollution indices as useful tools for the comprehensive evaluation of the degree of soil contamination–A review. Environmental Geochemistry and Health, 40(6), 2395–2420.
19. Krishna A.K, Mohan, K.R. 2016. Distribution, correlation, ecological and health risk assessment of heavy metal contamination in surface soils around an industrial area, Hyderabad, India. Environ Earth Sci, 75, 411.
20. Long Z., Huang Y., Zhang W., Shi Z., Yu D., Chen Y., Liu C., Wang R. 2021. Effect of different industrial activities on soil heavy metal pollution, ecological risk, and health risk. Environmental Monitoring and Assessment, 193(1), 193.
21. Ma L., Yang Z., Li L., Wang L. 2016. Source identification and risk assessment of heavy metal contaminations in urban soils of Changsha, a mine-impacted city in southern China. Environ. Sci. Pollut. Res., 23, 17058–17066.
22. Mamat Z., Yimit H., Ji R.Z.A., Eziz M. 2014. Source identification and hazardous risk delineation of heavy metal contamination in Yanqi basin,

northwest China. Science of the Total Environment, 493, 1098–1111.

23. Ministry of Natural Resources and Environment 2015. National technical regulation on the allowable limits of heavy metals in the soils (QCVN 03-MT:2015/BTNMT). MoNRE, Hanoi, Vietnam.
24. Ministry of Science and Technology 2005. National standard 7538-2:2005 (ISO 10381-2:2002) on soil quality-sampling-part 2: guidance on sampling techniques. Ministry of Science and Technology, Hanoi, Vietnam.
25. Ministry of Science and Technology 2009. National standard TCVN 8246:2009 (EPA Method 7000B) on soil quality – flame atomic absorption spectrophotometry. Ministry of Science and Technology, Hanoi, Vietnam.
26. Mordhorst A., Zimmermann I., Fleige H., Horn R. 2022. Environmental risk of (heavy) metal release from urns into cemetery soils. Science of the Total Environment, 817, 152952.
27. Olawoyin R., Oyewole S.A., Grayson R.L. 2012. Potential risk effect from elevated levels of soil heavy metals on human health in the Niger delta. Ecotoxicology and Environmental Safety, 85, 120–130.
28. Quang T.D., Trang N.T.K 2018. Current status and some technical and environmental solutions in the exploitation of stone building materials in An Giang Province. Journal of Science and Technology Mining-Geology, 59(5), 77–84.
29. Solgi E., Abbas E.S., Alireza R.B., Hadipour M. 2012. Soil contamination of metals in the three industrial estates, Arak, Iran. Bulletin of Environmental Contamination and Toxicology, 88(4), 634–638.
30. Sun Y. 2017. Ecological risk evaluation of heavy metal pollution in soil based on simulation. Polish Journal of Environmental Studies, 26(4), 1693–1699.
31. Thongyuan S., Khantamoon T., Aendo P., Binot A., Tulayakul P. 2020. Ecological and health risk assessment, carcinogenic and noncarcinogenic effects of heavy metals contamination in the soil from municipal solid waste landfill in Central, Thailand. Human and Ecological Risk Assessment: An International Journal, 21(4), 876–897.
32. Trinh L.T., Trang K.T.T., Trung N.T., Linh N.K., Tham T.T. 2018. Heavy metal accumulation and potential ecological risk assessment of surface sediments from Day river downstream. VNU Journal of Science: Earth and Environmental Sciences, 34(4), 140–147.
33. Wei B., Yang L. 2010. A review of heavy metal contaminations in urban soils, urban road dusts and agricultural soils from China. Microchemical Journal, 94(2), 99–107.
34. Wu Q., Hu W., Wang H., Liu P., Wang X., Huang B. 2021. Spatial distribution, ecological risk and sources of heavy metals in soils from a typical economic development area, Southeastern China. Science of The Total Environment, 780, 146557.
35. Zhang X.Y., Lin F.F., Wong M.T.F., Feng X.L., Wang K. 2009. Identification of soil heavy metal sources from anthropogenic activities and pollution assessment of Fuyang County, China. Environmental Monitoring and Assessment, 154(1–4), 439–449.