Evaluating Ecological Risk Associated with Heavy Metals in Agricultural Soil in Dong Thap Province, Vietnam

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ABSTRACT

Heavy metal pollution in soil has received more attention in recent years because of an increase in human activities and its potential effects on ecology and human health. This study assessed the occurrence of heavy metals (As, Pb, Cu, Zn, and Cd) in different cultivated land and their ecological risk in Dong Thap Province, Vietnam. Seventeen samples collected in paddy, vegetable, perennials, and ornamental soils were measured for heavy metal concentrations and soil structure. The data were analyzed using Pearson correlation, principal component analysis (PCA), cluster analysis (CA), Nemerow pollution index (PI_N), geoaccumulation index (I_{geo}), pollution load index (PLI), and potential ecological risk index (RI). The results revealed that the soil structure was clay loam and silt clay loam. Heavy metal concentrations were within the national limits with the order of Zn>Cu>Pb>As>Cd. Pearson correlation and PCA indicated that heavy metals were strongly correlated, and agriculture and soil formation were responsible for their presence in soil. The sampling sites were divided into four groups using CA, in which paddy and crop soils had the highest content of heavy metals. Based on PI_N values (0.82-2.92), the heavy metal pollution ranged from warning to moderate level. As had the highest accumulation potential in the soil, with the I_{geo} values ranging from 0.12-2.05. The risk of heavy metal pollution in agricultural soil to ecology was low to moderate. Despite that, it is recommended to annually monitor the occurrence of heavy metals in agricultural soils to have proper solutions to protect public health.

1. INTRODUCTION

Heavy metals are defined as metallic elements whose density is at least five times higher than water (Fergusson, 1990). Based on this definition, heavy metals include metalloids such as arsenic (As) with a density of 5.73 g/cm^3 (Duffus, 2002; Tchounwou et al., 2012). Heavy metals are naturally occurring elements in the earth's crust. As a result of rapid urbanization and industrialization, an increase in heavy metal pollution has become a significant concern (Apostol et al., 2021; Fei et al., 2022). Heavy metals are persistent and non-biodegradable, which are likely to disperse and accumulate in ecosystems, eventually entering the human body through the food chain (Klinsawathom et al., 2017; Rashed, 2018). Some heavy metals, such as cadmium (Cd), chromium (Cr), arsenic (As), mercury (Hg), lead (Pb), copper (Cu), zinc (Zn), and nickel (Ni), have been listed as priority pollutants for control by the United States Environmental Protection Agency (USEPA) (Cravotta and Brady, 2015). Heavy metal accumulation in the human body can cause serious diseases, such as Cd damaging kidney function (Liu et al., 2022) and As causing cardiovascular disease, diabetes, and cancer (Li et al., 2016). Therefore, it is necessary to evaluate heavy metal contamination in soil and determine their potential risks.

The presence of heavy metals in soil is attributed to two primary sources. Firstly, natural processes such as weathering and volcanism are associated with heavy metal pollution (Fei et al., 2022; Cui et al., 2021). The impacts of anthropogenic activities are prominent, including mining and smelting industries, metal-based industries, domestic wastes, and agriculture (Wei and Yang, 2010; Huan et al., 2017; Guan et al., 2019; Cui et al., 2021; Fei et al., 2022). In terms of the impact of agricultural activities, applying heavy metal-

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containing pesticides and herbicides greatly contributes to soil pollution. For example, As contamination in cultivated land was associated with the excessive application of pesticides (Cai et al., 2019; Jiang et al., 2020; Fei et al., 2022). Using phosphate fertilizers and pesticides is a reason for the high content of Cd in Shanghai (Fei et al., 2022). In addition, using contaminated water for irrigation has caused the enrichment of heavy metals in the agricultural system (Hung and Thom, 2016). In recent years, many countries have intensively increased agricultural activities to ensure food safety which is one of 17 sustainable development goals (SDGs). This has led to a high risk of heavy metal contamination in the agricultural soil. There are several factors that control the concentrations of heavy metals in soil: wind direction, topography, and particle size distribution (Lou et al., 2022). However, the number of studies on heavy metals in agricultural soils and their potential environmental risks are limited (Fei et al., 2022).

In recent studies, different indices have been introduced to assess the extent of pollution and the potential pollution of agricultural soil by heavy metals, such as Nemerow pollution index (PI_N), geoaccumulation index (I_{geo}), pollution load index (PLI), and potential ecological risk index (RI) (Fei et al., 2022; Kowalska et al., 2018; Cui et al., 2021; Kang et al., 2020). PI_N is calculated to evaluate the overall pollution of soil and determine the most polluted parameters (Kowalska et al., 2018). Similar to PI_N, PLI is used to assess the pollution levels or the levels of heavy metals in soil, which can be used to compare the soil quality between different study areas (Nazzal et al., 2021; Ferreira et al., 2022). I_{geo} index is employed to assess the pollution extent in soil by each heavy metal, which can compare the changes in the soil problems in the past and the present (Kowalska et al., 2018; Nazzal et al., 2021; Ferreira et al., 2022). To evaluate the potential risks to ecology by heavy metal-contaminated soils, RI is employed with the consideration of toxic level, ecological sensitivity, and synergy effects of heavy metals (Cui et al., 2021; Ferreira et al., 2022). These indices are deemed effective tools to comprehensively evaluate soil contamination and predict the effects on ecology (Kowalska et al., 2018). However, the application of a single index could not provide a full understanding of the pollution extent (Kowalska et al., 2018; Fei et al., 2022). Thus, it is required to combine different indices to generate comprehensive information related to soil pollution by heavy metals, which supports policymakers in developing sustainable development strategies.

In Vietnam, agricultural production is one of the most important economic sectors, especially in two primary deltas (Red River delta and Mekong Delta). In the Red River delta, high As content was found in vegetable land (Ha et al., 2016). Collected soil samples in the vegetable growing area showed the signal of Cu, Cd, and Pb contamination (Huan et al., 2017). In Mekong Delta, the natural land area is mainly used for agricultural cultivation, about 2,615.6 thousand hectares, accounting for approximately 64.08% of the total area (General Statistics Office of Vietnam, 2022). According to Huynh et al. (2022), several heavy metals (As, Pb, Cu, Zn) were detected in An Giang Province. Nevertheless, studies about heavy metals in different agricultural soils in the Mekong Delta remain limited. Thus, this study was conducted to evaluate soil characteristics and identify sources and ecological risk associated with the occurrence of heavy metals in agricultural soil using multivariate statistics, Nemerow pollution index (PI_N), geological accumulation index (I_{geo}), pollutant load index (PLI) and ecological potential risk index (RI). The findings could provide helpful information on the agricultural soil pollution levels in Dong Thap Province to formulate strategies for agricultural safety and sustainability.

2. METHODOLOGY

2.1 Description of the study area

Dong Thap is located in Mekong Delta with the coordinates of 10°07′ to 10°58′ North latitude and 105°12′ to 105°56′ East longitude, which is adjacent to Cambodia (North), Vinh Long Province and Can Tho City (South), An Giang Province (West), Long An and Tien Giang Provinces (East). Dong Thap has a fairly flat terrain, and the whole province is located in the delta region. The elevation difference is not large, with an average of about 2 m. The province has three types of terrain: natural dykes along the Tien and Hau Rivers, behind the dyke, and low-lying fields (closed floodplains). Land resources of Dong Thap Province are classified into four main soil types. Alluvial and alkaline soils have the largest area, with an area of 183.9 thousand hectares and 92.4 thousand hectares, respectively. They are distributed mainly along the Tien and Hau Rivers (alluvial soil), Tam Nong and Thap Muoi Districts (alkaline soil). Gray soil is mainly found in Tan Hong District bordering Cambodia and Tam Nong District, about 26.5 thousand hectares.

Sandy soil is distributed in Thap Muoi and Cao Lanh Districts with 0.067 thousand hectares.

The structure of land use in agriculture in Dong Thap Province in 2019 is divided into two categories: annual cropland (accounting for 227.3 thousand hectares) and perennial cropland (accounting for 32.80 thousand hectares). The annual cropland is used mainly for rice cultivation, with about 221.5 thousand hectares (accounting for 65.47%). Dong Thap Province has a total natural land area in 2019 of 338.4 thousand hectares, of which agricultural production land accounts for 76.84% with 260.1 thousand hectares (DoNRE, 2021). Therefore, it is considered one of the provinces with agricultural land accounting for a high proportion of the total natural land area. The agricultural system of Dong Thap Province is diverse with many other agricultural cultivation models, such as rice, vegetables, fruit trees, and ornamental plants.

2.2 Soil sample collection and analysis

Seventeen agricultural soil samples (D01-D17) were collected twice in 2020. The sampling sites are presented in Figure 1. The soil samples were collected at different agricultural cultivation areas in Dong Thap Province, including rice, vegetables, perennials, and ornamental plants. These collected soil samples were then analyzed for soil structure and heavy metals (As, Pb, Cu, Zn, and Cd). Soil samples were collected and preserved according to the standards specified in the national standard TCVN 5297:1995 on Soil Quality-Sampling-General requirements (MOST, 1995) and the national standard TCVN 7538-2:2005 in the Soil Quality-Sampling-Part 2: Guidance on sampling techniques (MOST, 2005). The collected soil samples were dried in an oven and then ground to pass through a 0.5 mm stainless steel mesh. The heavy metal concentrations in the soil were measured according to the national standard TCVN 6496:2009 on Soil quality - Determination of cadmium, chromium, cobalt, copper, lead, manganese, nickel, and zinc in aqua regia extracts of soil - Flame and electrothermal atomic absorption spectrometric methods (Varian SpectrAA Model 220FS, US) (MOST, 2009). The detection limits of these heavy metals were 0.01 mg/kg. The sample collection and analysis were strictly conducted to ensure quality assurance/quality control (QA/QC). Three field samples were obtained from one location and preserved in a separate container. In the laboratory, blank samples, verification standard samples, and duplicate laboratory samples were measured.

2.3 Data processing

2.3.1 Statistical analysis

The data of heavy metals were analyzed to determine the values of min, max, mean, standard deviation, and coefficient of variation (CV). To assess the current status and evolution of soil environmental quality in Dong Thap Province, the heavy metals in the soil were compared with QCVN 03-MT:2015/BTNMT-National technical regulation on heavy metal content for agricultural soil (MoNRE, 2015). Correlation analysis was performed to determine the relationship between soil properties and heavy metals (Qishlaqi and Moore, 2007; Zhu et al., 2017). In addition, the principal component analysis (PCA) and cluster analysis (CA) were applied based on the mean of the parameters. PCA aims to determine the most significant parameters affecting soil quality. On the other hand, PCA was also used to determine the origin of heavy metals in the soil. Moreover, CA can group the sampling locations with similar soil properties (Yang et al., 2014; Zhang et al., 2016; Nazzal et al., 2021). The analytical methods were performed using the statistical software Statgraphics Centurion version XVI (Statgraphics Technologies Inc., Virginia, USA).

2.3.2 Ecological risk and pollution level calculation

The Nemerow pollution index (PI_N), cumulative geographic index (I_{geo}), pollution load index (PLI), and potential ecological risk index (RI) were applied to quantify pollution level and potential risk of heavy metals in agricultural soil.

The single pollution index (PI) is used to evaluate the pollution level of each heavy metal in soil (Kowalska et al., 2018). Meanwhile, the accumulation level of each heavy metal in the soil was assessed by geoaccumulation index (I_{geo}) (Kowalska et al., 2018; Cui et al., 2021). The values of indexes were calculated by the equation (1) and (2):

$$PI = \frac{C_n}{GB} \quad (1)$$

$$I_{geo} = \log_2 \left(\frac{C_n}{1.5GB}\right) \quad (2)$$

The spatial variation of I_{geo} values was conducted by the Arcgis version 10.2 software. It was based on interpolation with the inverse distance weighted method.

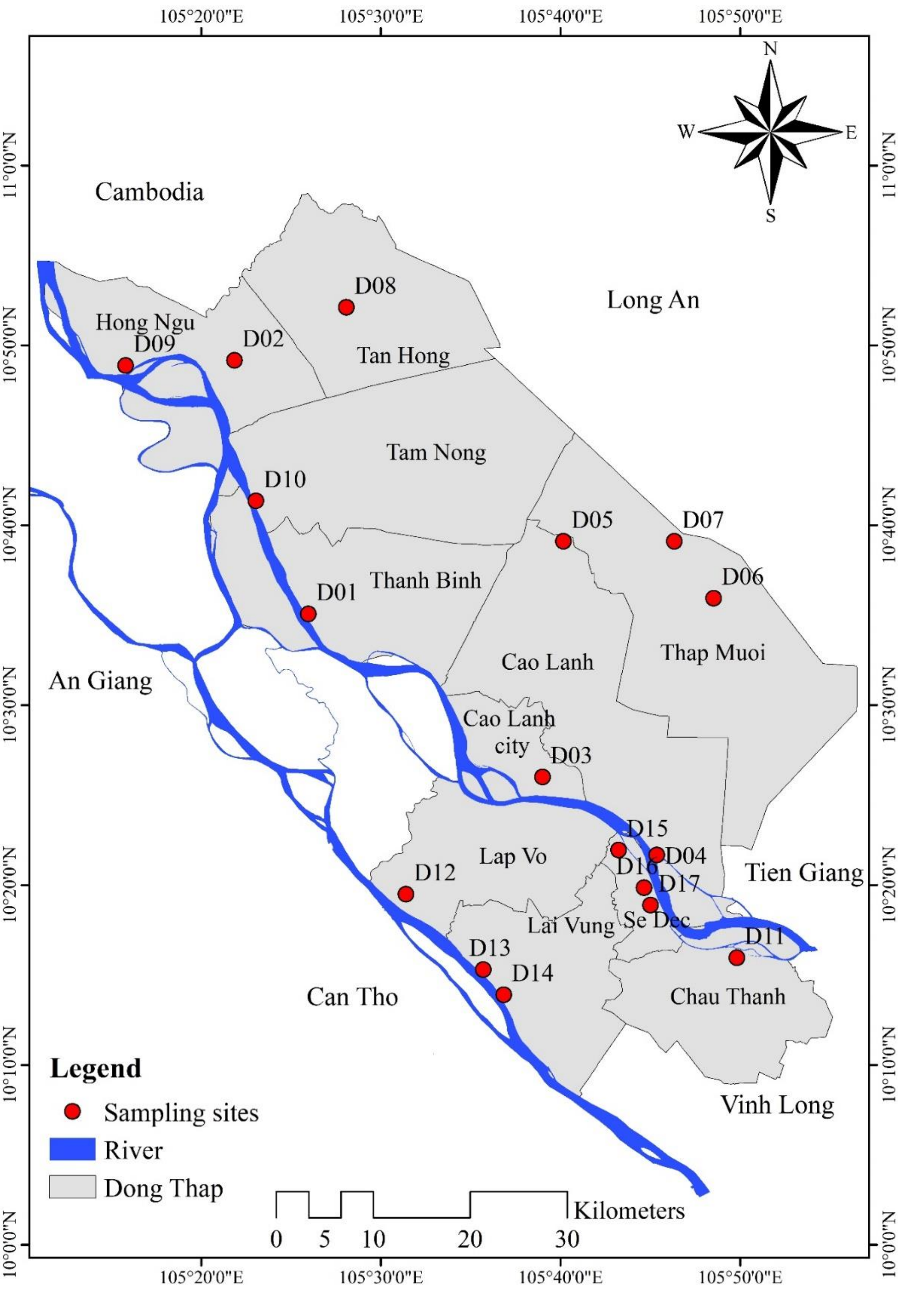

Figure 1. Location of soil sample collection in Dong Thap Province

The overall pollution level of heavy metals in the soil was determined through two indexes (PI_N and PLI). These two indexes were calculated by formulas (3) and (4) (Kowalska et al., 2018; Mamut et al., 2018; Kang et al., 2020):

$$PI_N = \sqrt{\frac{\left(\frac{1}{n}\sum_{i=1}^{n} PI\right)^2 + PI_{max}^2}{n}} \quad (3)$$

$$PLI = \sqrt[n]{PI_1 \times PI_2 \times PI_3 \times \ldots \times PI_n} \quad (4)$$

In addition, the potential ecological risk (RI) was used to assess potential risks that heavy metals pose to the ecology of the study area (Hakanson, 1980; Ramdani et al., 2018):

$$RI = \sum_{i=1}^{n} E_r^i = \sum_{i=1}^{n} T_r^i \times PI \qquad (5)$$

Where, C_n is heavy metal content in analyzed soil samples; GB 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 mg/kg, respectively (Kabata-Pendias, 2010; Kowalska et al., 2018); PI_{max} is the 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). The reference values of each index in the study are detailed in Table 1.

Table 1. Pollution and risk rating scale

Index	Values	Rating	Index	Values	Rating
PLI	PLI≤1	No pollution	RI	RI<50	Low
	1<PLI≤2	Moderate		50≤RI<100	Moderate
	2<PLI≤3	High		100≤RI<200	High
	PLI>3	Extremely high		RI≥200	Very high
PI_N	PI_N≤0.7	Safe level	I_{geo}	I_{geo}≤0	No pollution
	0.7<PI_N≤1	Warning limit		0<I_{geo}≤1	No to moderate
	1<PI_N≤2	Slight pollution		1<I_{geo}≤2	Moderate
	2<PI_N≤3	Moderate pollution		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

3. RESULTS AND DISCUSSION

3.1 Soil structure properties

The change in soil structure is considered a factor affecting the fluctuation in soil chemical composition (Wang et al., 2018). The analysis results of the structure of agricultural soil are presented in Figure 2. The percentage of clay and silt was high in this study area, which was about 32.57±3.82% and 44.87±5.87%, respectively. Meanwhile, that of sand only fluctuated around 22.56±4.95%. Based on the soil structure triangle classified by Soil Survey Staff (1999), the results showed that the soil in Dong Thap mainly belongs to the clay loam and silty clay loam groups (Figure 2). Soil particle-size distribution will affect the organic matter content in the soil (Wang et al., 2018). This can affect the mobility and accumulation of heavy metals in the soil. Specifically, agricultural land in the study area is assessed to have a higher ability to absorb and retain nutrients and heavy metals (Wang et al., 2018).

3.2 Concentrations of heavy metals

In agricultural soils, heavy metal pollution can negatively impact soil properties, reduce the yield and quality of agricultural products, and consequently affect human and animal health (Hung and Thom, 2016). The results of heavy metal concentration in agricultural soils in Dong Thap Province are shown in Table 2. The Cu content fluctuated in the range of 18.53-44.48 mg/kg, with an average of 27.28±7.24 mg/kg. In Mekong Delta, the Cu concentration varied from 20.1-43.0 mg/kg (Nguyen et al., 2020), which is consistent with the current study. However, the Cu concentration in agricultural soils along the Tarim basin (Xinjiang, China) is generally lower than in the present study area, ranging from 16.4±3.22 to 21.97±7.6 mg/kg (Fan et al., 2019). High Cu concentration in agricultural land is attributed to weathering and trace fertilizers. In addition, the high concentration of Cu in the soil is partly due to the influence of domestic wastewater (Thu et al., 2018).

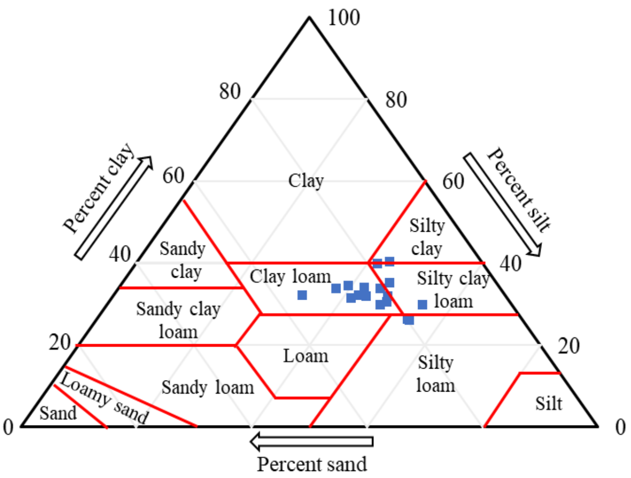

Figure 2. Triangle of soil structure in the study area

In the earth's crust, the Zn concentration is about 75 mg/kg and about 50 mg/kg in soil (Nazzal et al., 2021). The results revealed that the relatively high Zn content was found in the range of 104.30 to 195.49 mg/kg, with an average of 143.96±29.62 mg/kg. According to Marrugo-Negrete et al. (2017), the Zn content in the soil Sinu River Basin (Colombia) was found to be the highest among other heavy metals. This is consistent with the results of the present study. In the Mekong Delta, the Zn concentration was recorded at about 90 mg/kg in soil (Nguyen et al., 2020). In addition, the previous study by Ramdani et al. (2018) found that Zn in the agricultural area ranged from 52.5 to 1,952.5 mg/kg, with an average of 126.8±510.7 mg/kg. This analysis indicated that Zn concentration increased significantly in agricultural soil in Dong Thap Province. This range of Zn concentration could be affected by anthropogenic sources (Ramdani et al., 2018).

Table 2. The concentration of heavy metals in agricultural soil in the study area

Parameters	Range	Minimum	Maximum	Mean	Standard deviation	%CV	Vietnamese standard
Cu	25.95	18.53	44.48	27.28	7.24	26.54	100
Zn	91.19	104.30	195.49	143.96	29.62	20.58	200
As	3.08	1.09	4.17	2.51	0.93	37.16	15
Pb	6.39	5.98	12.37	8.56	1.82	21.27	70
Cd	0.08	0.05	0.12	0.07	0.02	30.41	1.5

The concentration of Pb varied from 5.98 to 12.37 mg/kg, reaching an average of 8.56±1.82 mg/kg. The lowest and highest concentration was both found in soil for farming vegetables. It can be seen that the concentration of Pb in the soil depends on the soil characteristics and the doses of agrochemicals used or wastes from the surrounding areas. Compared with the study of Nguyen et al. (2020) and Ha et al. (2016), the Pb concentration in agricultural soil in the Mekong Delta region (28.6±18.5 mg/kg) and Hanoi Capital (17.3-42.0 mg/kg) was higher than that in the study area. The use of herbicides, insecticides, and gasoline combustion in treating rice straws are the potential sources of Pb generation in the soil (Guan et al., 2019).

The arsenic concentrations ranged from 1.01 to 4.17 mg/kg, with an average of 2.51±0.93 mg/kg. Compared with the study of Hung and Thom (2016), the As concentration in agricultural soil fluctuated higher from 2.56 to 5.15 mg/kg, and the highest concentration was found in the paddy field. According to Nguyen et al. (2020), the As concentration was found in the range of 8.3-28.9 mg/kg in the Mekong Delta region, which was significantly higher than that of the study area. Ren et al. (2019) and Rostami et al. (2021) suggested that As concentration in agricultural soil increased after using phosphate fertilizers and pesticides over long periods of time.

The average Cd concentration in the study area was 0.07±0.02 mg/kg, ranging from 0.05 to 0.12 mg/kg. The lowest was found at position D12, and the highest was found at location D8. Former studies found that higher Cd concentrations ranging from 2.20 to 2.72 mg/kg exceeded the permissible limit (Huan et al., 2017). However, the Cd contents in the Mekong Delta varied from 0.16-0.43 mg/kg (Nguyen et al., 2020). According to Pan et al. (2016), the application of phosphate fertilizers is considered a major source of Cd in the environment. In addition, inorganic fertilizers such as nitrogen or potassium have significant Cd concentrations, which are sources of Cd in the soil (Cai et al., 2012). Other Cd sources are wastewater, sewage sludge, pesticides, fertilizers, and industrial emissions (Aboubakar et al., 2021).

It was found that the heavy metal contents in agricultural soil in Dong Thap province increased gradually in the order of Cd<As<Pb<Cu<Zn. Based on the coefficient of variation, the contents of heavy metals showed obvious spatial variability with the range of 20.58-37.16%. Spatial variability of heavy metals was explained by different types of agriculture having different effects on the concentration of heavy metals in the soil (Ren et al., 2019). The enrichment of heavy metals in agricultural soil is related to the supply of inputs for agricultural production, such as fertilizers and pesticides (Aboubakar et al., 2021). Compared with the national standard in QCVN 03-MT:2015/BTNMT-agricultural soil (MoNRE, 2015), the concentration of heavy metals is still within limits.

3.3 Correlation between soil parameters in the study area

The results of the Pearson correlation analysis between heavy metals in soil are presented in Table 3. There was a positive correlation between As, Pb, Cu, and Zn ($p<0.01$). Meanwhile, Cd was only found to be positively correlated with Pb ($r=0.55$) and Cu ($r=0.45$) in soil. The strong correlation between heavy metals showed that these elements are derived from the same source, which is human activities (Marrugo-Negrete et al., 2017; Wu et al., 2022). In addition, the high content of As, Pb, Cu, and Zn also indicated that pollution level is affected not only by the intrinsic properties of the soil but also by long-term agricultural activities (Zhu et al., 2017; Wu et al., 2022). In addition, the analysis also showed a high correlation of soil particles, including sand, clay and silt. However, the results only recorded a significant correlation between the percentage of sandy soil and Cu, which had a negative correlation ($r=-0.48$).

Table 3. Correlation between heavy metals and soil structure in agricultural soil

Parameter	As	Pb	Cu	Zn	Cd	Sand	Silt
Pb	0.56**						
Cu	0.49**	0.73**					
Zn	0.63**	0.6**	0.41**				
Cd	0.34	0.55**	0.45**	0.23			
Sand	-0.39	-0.33	-0.48**	-0.28	-0.26		
Silt	0.34	0.13	0.22	0.09	0.08	-0.68**	
Clay	-0.06	0.15	0.2	0.17	0.17	-0.112	-0.66**
Range	-1			0			1

**Correlation is significant at the level of 0.01; *Correlation is significant at the level of 0.05.

3.4 The main factors affecting the soil quality in the study area

PCA analysis was used to extract principal components (PCs) that can detect and identify sources of heavy metal contamination. In this analysis, only the components with eigenvalues greater than 1 are retained (Nazzal et al., 2021). The analysis results showed that there were three main components extracted, explaining 82.14% of the variations of heavy metals in the study area (Table 4).

Table 4. Principal component analysis results

Variable	PC1	PC2	PC3	PC4	PC5	PC6	PC7
As	0.40	-0.12	-0.42	0.13	0.05	-0.75	-0.25
Pb	0.45	0.16	-0.14	-0.07	-0.26	0.49	-0.66
Cu	0.43	0.08	0.17	-0.31	-0.67	-0.13	0.48
Zn	0.38	0.08	-0.52	-0.19	0.47	0.33	0.46
Cd	0.32	0.28	0.23	0.85	0.04	0.08	0.20
Sand	-0.37	0.28	-0.53	0.18	-0.37	0.04	0.08
Silt	0.23	-0.64	0.22	0.05	0.09	0.11	0.01
Clay	0.11	0.62	0.35	-0.31	0.34	-0.22	-0.12
Eigenvalues	3.74	1.82	1.02	0.57	0.41	0.30	0.14
%Variation	46.70	22.75	12.69	7.12	5.17	3.76	1.81
Cum.%Variation	46.70	69.44	82.14	89.26	94.43	98.19	100.00

The first principal component (PC1) explained 46.70% of the total variance of heavy metals. PC1 had positive loadings for As (0.40), Pb (0.45), Cu (0.43), Zn (0.38), Cd (0.32), and was the most important component. PC1 could explain the anthropogenic origin of heavy metals, specifically related to long-term agricultural activities in the study area. Several previous studies have noted that P-containing fertilizers used in vegetable cultivation also contain Pb, Cd and others (Yang et al., 2014; Wu et al., 2022). In addition, the contribution of heavy metals in this PC can originate from the formation of soil structure in the study area, namely Cd. The second principal component (PC2) accounted for 22.75% of total variance, which was contributed by the ratio of clay (0.62) and silt (-0.64). This component describes the effects of soil structure in the study areas. PC3 explained 12.69% of the variation correlated with As (-0.42) and Zn (-0.52). Although the presence of As and Zn may be the results of anthropogenic activities, this probably comes from different sources with previous PCs. The eigenvalues of PC4 were less than 1, accounting for 7.10% of the variation. However, PC4 was very strongly correlated with Cd (-0.85). In general, the heavy metals have contributed to soil quality variability in the study area. Excessive use of pesticides and inorganic fertilizers in farming can lead to the formation of heavy metals such as Cu, Zn, Pb, Cd, and As in the soil (Huang et al., 2010; Yang et al., 2014).

3.5 Clustering soil quality based on heavy metal concentrations

Four groups of sampling locations were obtained from CA method and the characteristics of each group are presented in Figure 3 and Table 5. Group I consisted of four sites D01, D05, D11, and D15, with relative similar soil quality (accounted for 25.53% of the total locations), which were located in the rice-growing areas. The average concentrations of As, Pb and Cu were 2.74, 8.35, and 24.13 mg/kg, respectively. The concentrations of Zn and Cd in this group were 154.25 and 0.08 mg/kg, respectively. Group III had 3 sampling sites (D02, D06, and D07), accounting for 17.65% of the total locations. These sites were also identified in the rice cultivation area. However, the proportion of clay and silt particles was higher than in Group I. Meanwhile, Group II gathered seven locations with similar soil quality, namely D03, D04, D12, D13, D14, D16, and D17, accounting for 41.18%. The locations in Group II have been identified as perennial crops, vegetables and ornamental plants. Group II had the lowest concentration of heavy metals in the soil. Finally, Group IV included D08, D09, and D10, accounting for 17.65%. The heavy metal content in group IV was the highest among the four soil groups.

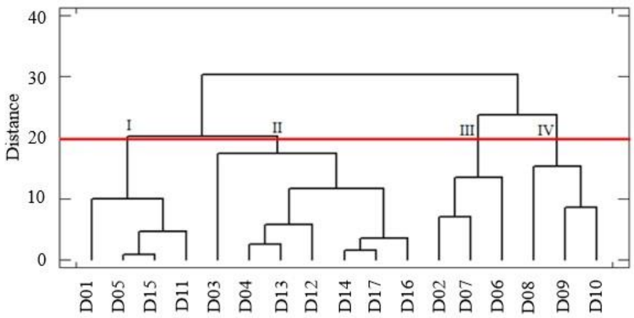

Figure 3. Clustering soil quality in the study area

Table 5. Heavy metals concentrations in the identified groups

Cluster	As (mg/kg)	Pb (mg/kg)	Cu (mg/kg)	Zn (mg/kg)	Cd (mg/kg)	Sand (%)	Silt (%)	Clay (%)
I	2.74	8.35	24.13	154.25	0.08	23.86	43.00	33.16
II	1.67	7.22	22.22	121.47	0.05	25.43	42.48	32.10
III	3.56	9.63	31.44	157.98	0.07	18.38	54.20	27.44
IV	3.12	10.89	39.13	168.70	0.09	18.37	43.63	38.01

3.6 Assessment of pollution levels and ecological risks in the study area

The PI_N is an index used to assess the aggregate influence of heavy metals on the quality of the soil environment (Cui et al., 2021). The results showed that the PI_N fluctuated in the range of 0.82-2.92. This assessed heavy metals from a warning level to moderate pollution (Figure 4). Only D14 and D17 were recorded at a warning level, accounting for 11.76% of total samples. Eight soil samples (D03, D04, D05, D11, D12, D13, D15, and D16) were slightly contaminated, which accounted for 47.06%. These sites are found mainly in the southern part of Dong Thap Province, with the dominance of perennial crops. Meanwhile, seven sampling sites (D01, D02, D06, D07, D08, D09, and D10) for cultivating rice and vegetable crops were evaluated at moderate pollution levels, accounting for 41.18% of the total sampling sites. In addition, Figure 4 also shows that the average heavy metal pollution was distributed mainly in the north of Dong Thap Province. The findings were consistent with the cluster analysis by groups III and IV, which show the highest soil heavy metal content. It can be seen that agricultural cultivation activities have greatly affected the soil quality in the area. Therefore, it is necessary to take appropriate measures to improve and implement sustainable production in agriculture.

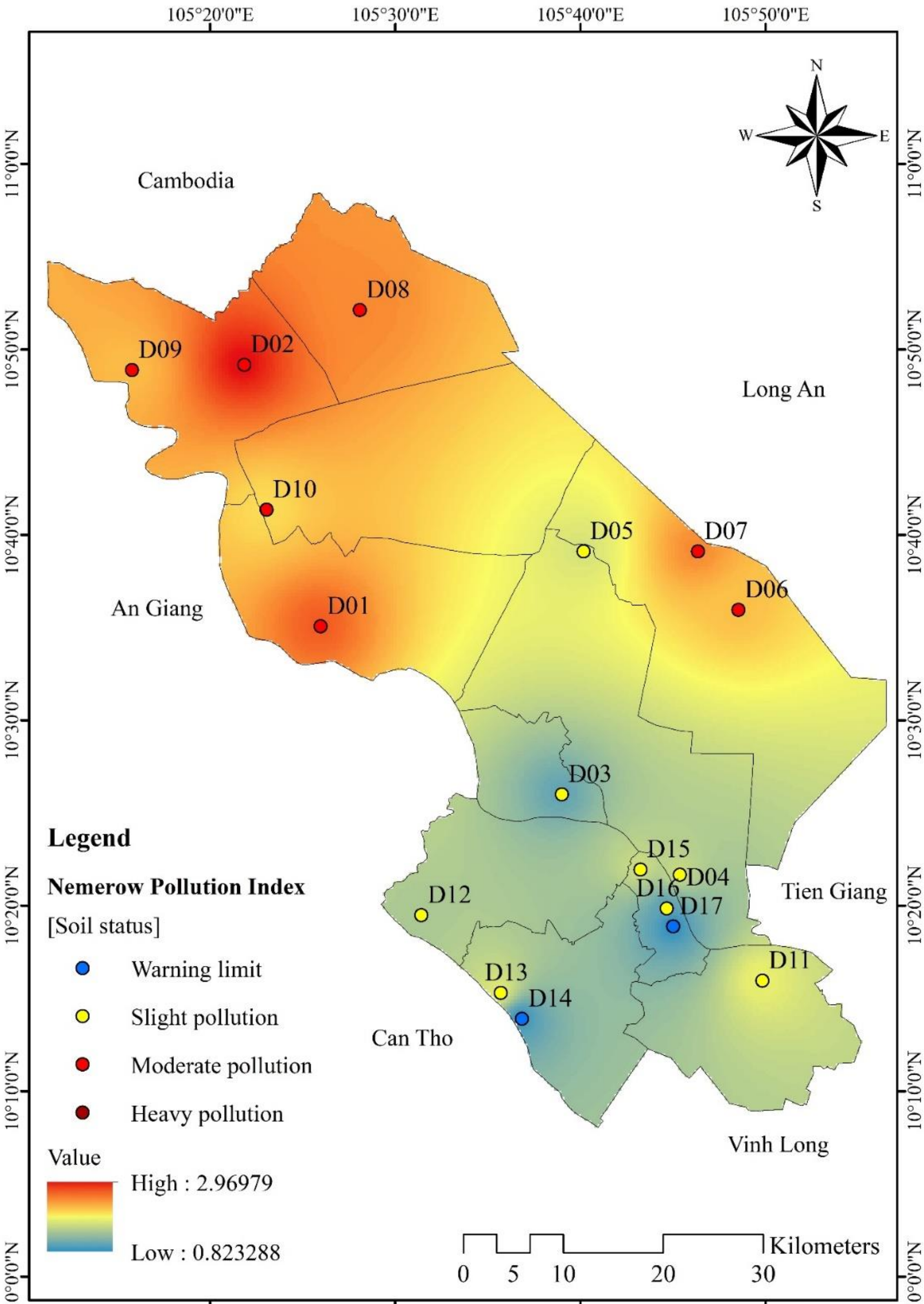

Figure 4. Values of PI_N at the study area

The I_{geo} values of Cu, Pb, and Cd were lower than 0; that is, there was no pollution of these heavy metals in soil. The contamination extent of As fluctuated from moderate to high, with the I_{geo} ranges of 0.12-2.05. The I_{geo} values of Zn were slightly lower than those of As, ranging from -0.01 to 0.90. The level of Zn pollution in soil was moderate. Specifically, the average values of I_{geo} index increased gradually from Cd(-3.20)<Pb(-2.27)<Cu(-1.14)<Zn(0.43)<As(1.21). The I_{geo} values of As and Zn in soil are presented in Figure 5(a) and Figure 5(b), respectively. The analysis results found that As and Zn accumulation was highest at D02 and D01 in rice-growing areas. According to Cai et al. (2012), As accumulated in agricultural soils is mainly derived from human activities, such as the inappropriate use of pesticides and fertilizers containing calcium and sodium arsenate. In superphosphate and granular fertilizers, Zn concentrations were approximately two and seven times higher, respectively, than the maximum

tolerable concentrations (Rostami et al., 2021). The trend of heavy metals accumulation was higher in the northern part of Dong Thap Province. This is explained by the soil structure is mainly clay and silt particles, which are more likely to accumulate heavy metals than sandy soils.

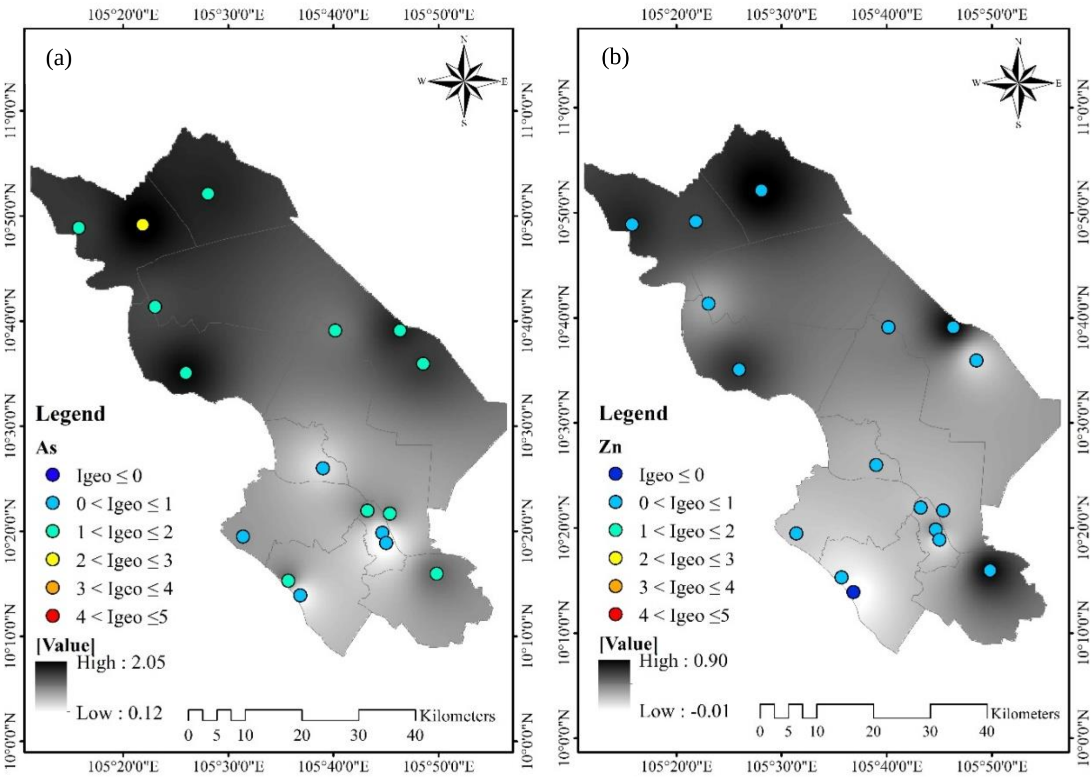

Figure 5. The values of I_{geo} of As (a) and Zn (b) in soil

The values of PLI ranged from 0.53 to 1.11 (Figure 6). Heavy metals in agricultural soils in the study area were at a non-polluted (94.1%) to moderately polluted level (5.9%). In addition, the values of RI ranged from 26.73 to 74.80. This has shown the potential ecological risk of heavy metals ranging from low (47.06%) to moderate (52.94%). It can be deduced that agricultural farming negatively impacts heavy metal contamination and risk to ecosystems. Excessive use of phosphate fertilizers increases the amount of phosphorus in the soil and leads to the accumulation of heavy metals in agricultural soils and pesticides (Marrugo-Negrete et al., 2017; Rostami et al., 2021). This information is useful for environmental managers in the agricultural sector to reconsider the cropping patterns and agricultural practices for sustainable development.

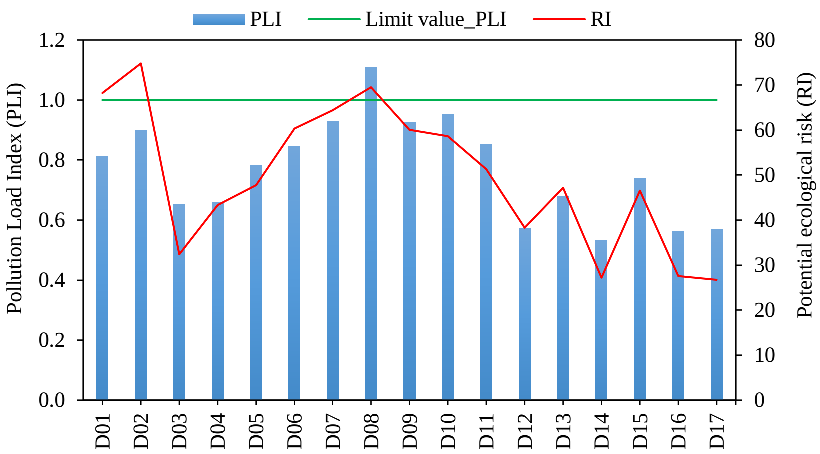

Figure 6. The values of PLI and RI in the study area

4. CONCLUSION

This study evaluated heavy metal contamination in various cultivated lands (rice, vegetables, perennials, ornamental plants) and potential ecological risks using multivariate statistics and pollution indices in Dong Thap Province, Vietnam. The soil structure in the study area was characterized by clay loam and silty clay loam groups. The results showed that the contents of heavy metals in agricultural soil were within the Vietnamese standard. Heavy metals (As, Pb, Cu, Zn, Cd) were strongly positively correlated. The results of PCA identified that agricultural practices contributed to the heavy metal pollution in the study area, especially in rice and vegetable-cultivated areas. Four different groups of sampling locations were obtained from CA, representing the effects of different agricultural practices on the presence of heavy metals. The PI_N index showed that the soil pollution by heavy metals was at the warning limit to moderate levels. As had the highest contribution to soil pollution in the study area. The PLI index reflected heavy metals in the soil ranging from non-polluted to moderately polluted. The ecological risk of heavy metal pollution was low to moderate. It should be noted that the impacts of heavy metals are cumulated, and the occurrence of several metals at the same time could accelerate the negative repercussions. Therefore, it is suggested to continue monitoring the concentration of heavy metals in soils for timely solutions to prevent the effects on ecology and human health.

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