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ECOLOGICAL RISK ASSOCIATED WITH THE OCCURRENCE OF HEAVY METALS IN AGRICULTURAL SOIL IN SOC TRANG PROVINCE, VIETNAM

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Abstract. The study aimed to evaluate the content and potential ecological risks due to the presence of toxic elements (Pb, Cu, Cr, Zn, As) in agricultural soil in Soc Trang province. Data of five heavy metals and physical factors at eight sites (from D1 to D8) in three ecological zones (fresh, brackish and saline agricultural activities) in the study were collected from the Department of Natural Resources and Environment of Soc Trang province. Multivariate statistical analyzes, including principal component analysis (PCA), correlation analysis (Pearson), cluster analysis (CA) and potential ecological risk index (RI), were used in the study. The results showed that the content of Pb, Cu, Cr, Zn and As fluctuated in the range of 8.54–30, 21.90–28.10, 20.60–38.70, 46.80–86, 1.35–11.30 mg/kg, respectively, within the allowable limits of QCVN 03-MT:2015/BTNMT. The soil in the study area has moderate to neutral acidity, suitable for growing crops. The Pearson and PCA results showed that the inputs in local agricultural development (fertilizers, pesticides, fungicides, and herbicides) have contributed to the increase of heavy metal content in the soil. The results of the CA grouped eight soil samples into two large groups belonging to the ecological areas (brackish, saline) and freshwater. The mean RI value of 68.84 indicated low potential ecological risks in agricultural land in Soc Trang province. However, As and Cr are heavy metals that would pose significant potential risks to the environment and humans. Thus, measures are needed to strictly control the sources of these metals.

Keywords: agricultural cultivation, ecological risks, heavy metals, soil pollution, Soc Trang Province

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INTRODUCTION

Soc Trang is a province specializing in agricultural production with a diverse and rich structure. In addition to rice, aquaculture is also considered a strength in promoting agricultural economic development, contributing to increasing the province's GRDP. Besides that, the province also has strengths in developing specialty fruit trees such as pomelo, mango and longan with an increasingly stable growing area, bringing a good source of income for gardeners. Not only that, but the area of vegetables also grows favorably and most can be mentioned are cabbage, scallions, purple onions, and bitter melon.

Along with agricultural development, the accumulation of heavy metals in the soil is also increasing, leading to environmental pollution. Heavy metals are often found in agricultural areas such as Pb, Cu, Cr and Zn. They originate from using pesticides, insecticides, fertilizers, untreated wastewater and surface water runoff from urban areas or industrial zones for irrigation, which have created a lot of heavy metals in agricultural land (Briffa *et al*. 2020, Mng'ong'o *et al*. 2021). When entering the soil, heavy metals increase the mineralization of organic matter, causing negative changes in the absorption complex in the soil due to the replacement of calcium and magnesium. The enzymatic activity of the soil decreases due to the reduced viability of useful microorganisms. The increased number of fungi causes the activity of many enzymes to be inhibited, leading to fertility degradation and reduced capacity for self-cleaning the soil (Baibotayeva *et al*. 2019). In addition, heavy metals are also found in groundwater and agricultural products (Musa *et al*. 2017, Vetrimurugan *et al*. 2017). This will lead to significant potential risks to human health when people use domestic water and agricultural products containing heavy metal residues (Briffa *et al*. 2020, Mng'ong'o *et al*. 2021). Therefore, the study was carried out to evaluate the heavy metal content and identify influencing factors in agricultural soil in Soc Trang province. From there, it can help managers set a direction for sustainable agricultural development, minimizing sources of heavy metal generation and environmental pollution.

MATERIALS AND METHODS

Study area description

Soc Trang is located in the lower part of Hau River, with coordinates 9°12'-9°56' north latitude and 105°33'-106°23' east longitude. The natural area is 3,311.8 km^2, suitable for developing paddy rice, short-term industrial crops and fruit trees. Currently, agricultural land is 276,677 ha, accounting for 82.89%, of which agricultural land is 205,748 ha, accounting for 62.13%, forestry land with 11,356 ha, accounting for 3.43%, 54,373 ha of aquaculture land, accounting for 16.42%, other agricultural accounts for 0.97%. Soc Trang's land consists of 6 main groups: (1) The sandy soil group has 8,491 ha, including the fields with light mechanical composition, from fine sand to sandy soil mixed with soil, some vegetables can be grown; (2) The alluvial soil group has 6,372 ha, fertile land suitable for growing rice crops and specialty fruit trees; (3) Soil group has 1,076 ha, in lowland areas usually one-crop rice is grown; (4) The saline soil group has 158,547 ha, divided into many types such as high saline soil, medium saline soil, low saline soil, etc., in which high saline soil occupies a large area suitable for growing rice, vegetables, fruit trees, short- and long-term industrial plants and other saline soils mainly for rice cultivation combined with aquaculture; (5) Acid soil group has 75,823 ha, including active acid soil and potential acid soil, mainly growing rice in combination with aquaculture; (6) The group of artificial land has 46,146 ha. Soc Trang province's land resources are pretty rich and diverse, with many types of cultivation and land use.

Data collection

Eight soil samples were collected to analyses of five heavy metals (Pb, Cu, Cr, Zn, As) and pH_{H2O}, pH_{KCl}. The soil samples were in agricultural areas representing the brackish water ecological area (D1) in Hoa Tu II commune and the saltwater ecological area (D2, D3) belonging to An Thanh Nam commune and Ward 2 Vinh Chau town. The rest was the freshwater ecological area (D4, D5, D6, D7, D8) in Nhon My commune, Truong Khanh commune, Ho Dac Kien commune, My Quoi commune and Chau Hung commune, respectively. The coordinates of the locations of the sampling points in the study area are shown in detail in Table 1.

Table 1. Coordinates of soil sampling locations in Soc Trang province

No.	Code	Commune	Coordinates		Ecological area
			Longitude	Latitude	
1	D1	Hoa Tu II	105°52'45.22	09°24'29.69	Brackish area
2	D2	An Thanh Nam	106°14'05.02	09°31'05.80	Saline area
3	D3	Ward 2, Vinh Chau town	106°01'26.05	09°19'49.98	Saline area
4	D4	Nhon My	106°00'45.06	09°48'31.46	Freshwater area
5	D5	Truong Khanh	105°59'41.87	09°40'45.82	Freshwater area
6	D6	Ho Dac Kien	105°51'16.45	09°43'23.68	Freshwater area
7	D7	My Quoi	105°34'23.28	09°28'04.71	Freshwater area
8	D8	Chau Hung	105°40'54.06	09°25'23.26	Freshwater area

Soil sampling and analysis

Soil samples in the study area were collected according to TCVN 5297:1995 – Soil quality – Sampling – General requirements and TCVN 7538-2:2005 – Soil quality – Sampling – Sampling technique manual, in depth no more than 20 cm, with a frequency of 1 time/year in April 2021. After the soil sample was collected, it was air-dried, removed the raw materials, and then grinded the dried sample through a sieve according to ISO 11464:2006 to analyze heavy metals of Pb, Cu, Cr, Zn and As by atomic absorption method (ASS). Specifically, Pb, Cu, Cr, and Zn were analyzed according to TCVN 6496: 2009 and As was analyzed according to TCVN 8467: 2010 (ISO 20280: 2007). Mainly for two physical parameters, pH_{H2O} and pH_{KCl}, the analysis was performed according to TCVN 5979:2007 (ISO 10390:2005).

Data processing

Data on heavy metal content and physical parameters in soil were synthesized and analyzed using SigmaPlot 14.0 software (Systat Software, Inc, US) to determine the locations with the lowest and highest concentrations of heavy metals and soil pH values, as well as the total average at eight monitoring locations. A box plot was used to present the results of this analysis. In a box chart, the middle bar represents the mean, and the top and bottom bars represent the first and third quartiles. Meanwhile, the two outermost symbols correspond to the lowest and the highest value. In addition, brackish, saline and freshwater ecological zones were also analyzed to determine the areas with the lowest and highest values of soil environmental indicators. The analysis results will be compared with QCVN 03-MT:2015/BTNMT national technical regulation on permissible limits of some heavy metals in soil in the case of agricultural land (Ministry of Natural Resources and Environment 2015).

Correlation analysis (Pearson) was performed based on the data of five heavy metals and physical factors (pH) of the soil. The results of correlation analysis will show that environmental factors have a linear relationship (Cai *et al*. 2012, Du *et al*. 2015, Qishlaqi and Moore 2007). According to Cai *et al.* (2012), when the heavy metals in soil are highly correlated, it can be reflected that these metals have similar formation origins. Pearson analysis was performed using SPSS 20.0 software (IBM Corp., Armonk, NY, USA).

Principal components analysis (PCA) can be used to reduce large numbers of data sets and extract a smaller number of independent factors (principal components) to analyze the relationship between essential variables (Cai *et al*. 2012). This method has been widely applied in many studies, likely sedimentary environment (Xia *et al*. 2018, Zhang *et al*. 2018), surface water (Liu *et al*. 2020, Mamun and An 2021), groundwater (Kaur *et al*. 2020, Rezaei *et al*. 2019) and soil environment (Hou *et al*. 2017, Shan *et al*. 2013) to identify sources of pollution arising, changing the quality of the monitoring environment. Principal components (PCs) with eigenvalues greater than 1 are retained to explain the variability of the dataset (Qishlaqi and Moore 2007). However, PCs with eigenvalues less than 1 but with close correlation coefficients between environmental variables and principal components, they are still kept for explanation (Wu *et al*. 2016). Data on heavy metals and spatially varying soil physical properties were used for this analysis. PCA was performed using Primer 5.2 software (PRIMER-E Ltd., Plymouth, UK).

Cluster analysis (CA) is effectively applied in classifying and grouping observed objects with similar properties (Bhuiyan *et al*. 2010, Khan *et al*. 2010). The tree diagram (dendrogram) was used to present the clustering results. Monitoring points with similar soil quality are in the same group and *vice versa*; different points are in different groups. In this study, CA was performed from data of seven environmental parameters at eight soil environmental monitoring points and analyzed using Primer 5.2 software (PRIMER-E Ltd., Plymouth, UK).

Ecological risk assessment

The potential ecological risk index (RI) is used to comprehensively assess the harmful effects of heavy metals in the environment and is calculated according to the equations (Du *et al*. 2015, Bhuiyan *et al*. 2021, Hakanson *et al*. 1980).

$$RI = \sum_{i=1}^{n} E_r^i = \sum_{i=1}^{n} T_r^i \text{ x } PI$$

In which: E^i_r is the potential ecological risk coefficient of each heavy metal with 5 risk levels including $E^i_r < 40$ – low risk, $40 \leq E^i_r < 80$ – medium risk, $80 \leq E^i_r < 160$ – significant risk, $160 \leq E^i_r < 320$ – high risk and $E^i_r \geq 320$ – very high risk (Bhuiyan *et al*. 2021, Hakanson *et al*. 1980); T^i_r represents the toxicity coefficient of heavy metals with Pb = Cu = 5, Cr = 2, Zn = 1 and As = 10 (Hakanson *et al*. 1980); The PI shows a single pollution index calculated by the formula Ci/Cn where *Ci* is the actual concentration of heavy metals and *Cn* is the background value, Pb = 15, Cu = 19.78, Cr = 3.4, Zn = 47.16 and As = 1.9, respectively (Kowalska *et al*. 2018). The potential ecological risk rating scale RI includes RI < 150 – low risk, 150 RI < 300 – moderate risk, 300 ≤ RI < 600 – significant risk and RI ≥ 600 – risk very high (Khan *et al*. 2010).

RESULTS AND DISCUSSION

Acidity and heavy metal concentrations in soil

The analysis results showed that the average pH in the soil at eight monitoring locations was relatively low (pH_{H2O} = 5.82±1.39 and pH_{KCl} = 5.45±1.41), with a range of pH_{H2O} activity ranged from 4.18 (Ho Dac Kien commune) to 7.37 (Nhon My commune). While the pH_{KCl} value ranged from 4 (My Quoi commune) to 7.08 (Ho Dac Kien commune) (Fig. 1a). Besides, pH_{H2O} and pH_{KCl} were highly concentrated in brackish water (7.14 and 6.92) and saltwater (6.94 and 6.48) ecological areas (Fig. 1b). Particularly for the freshwater ecological area with lower acidity, the soil has a neutral response to the pH value (Dang and Hung 1999). The reason may be that acidity in the saltwater environment is slightly reduced due to the neutralizing effect of some alkaline substances such as CO_3^{2-}, HCO_3^- and OH^- (Tho *et al*. 2017). For pH_{H2O} active acidity and pH_{KCl} exchange potential acidity in freshwater ecology, there are similarities with the study of Khoi *et al.* (2020); however, this value does not affect the growth of plants. In addition, the soil pH value in the freshwater eco-region is also well compared with the study of Chau *et al*. (2021), the case of soil quality assessment in freshwater farming models in the Cu Lao Dung district. High exchange acidity is a sign of sudden changes in pH when applying too much mineral fertilizer such as K_2SO_4, KCl and NH_4Cl. According to Ve (2013), if the soil is acidic for a long time, it will lead to a loss of color and reduced yield and quality of crops. In general, locations in brackish and saltwater areas, soil with neutral acidity, and freshwater areas with moderate acidity according to the rating scale of Dang and Hung (1999). For the case of acidic soil in the freshwater ecological area of Soc Trang province, liming is one of the effective measures that can prevent the degradation process, restore the soil structure and aerate and absorb water well (Chau *et al*. 2021).

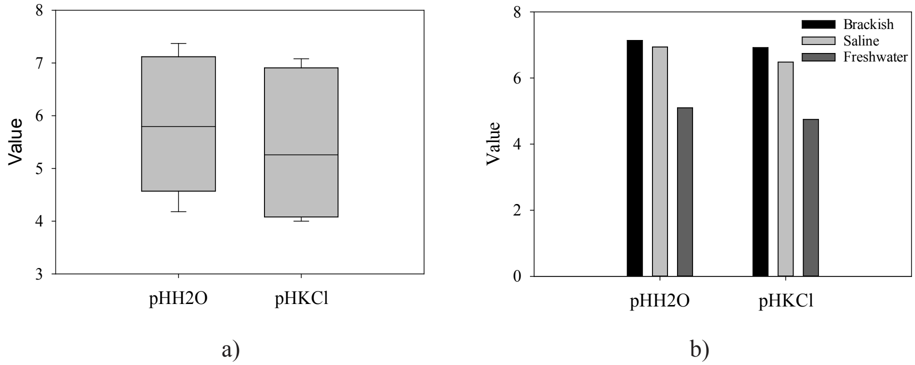

Fig. 1. The pH value of the soil at the observed locations (a) and ecological areas (b)

When considering the evolution of heavy metal content in the soil at the monitoring sites, the concentrations of Pb, Cu, Cr, Zn and As fluctuated in the range of 8.54–30 mg/kg; 21.90–28.10 mg/kg; 20.60–38.70 mg/kg; 46.80–86 mg/kg; 1.35–11.30 mg/kg, respectively and the average values correspond to 19.97±6.29 mg/kg; 26.14±2.06 mg/kg; 27.26±6.13 mg/kg; 66.56±14.50 mg/kg; and 7.24±3.36 mg/kg (Fig. 2a). This result indicates that the highest and lowest Pb concentrations in the soil were observed at the monitoring sites in Chau Hung and An Thanh Nam communes, respectively. As for Cu and Cr concentrations in the surveyed soil samples, the trend is lowest and highest at the monitoring location in Ward 2 and Truong Khanh commune. The Zn values in the soil in the study area are the lowest and the highest at the monitoring location in Hoa Tu 2 and My Quoi communes, respectively. Finally, As concentration was highest at Nhon My commune and lowest at Ho Dac Kien commune. In addition, when considering the fluctuations of heavy metal content in the soil in brackish, saline and freshwater ecological areas (Fig. 2b), the concentrations of Pb, Cu, Cr, Zn and As vary between 13 and 13.53–22.76 mg/kg, 24.85–27.80 mg/kg, 20.65–29.54 mg/kg, 60.42–86 mg/kg and 6.13–9.26 mg/kg, respectively. This result indicates that the two heavy metals (Cu and Zn) are most concentrated in the brackish ecological area. The heavy metals Pb and Cr tend to form high in the soil in the freshwater area, while the saltwater ecological area has the highest concentration of As.

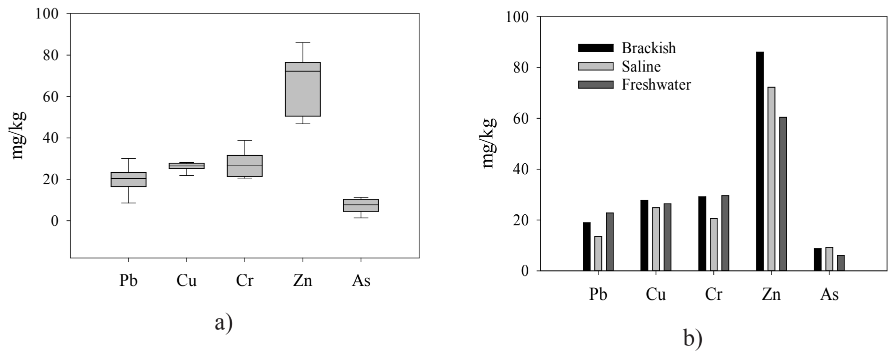

Fig. 2. Concentration of heavy metals in soil at locations (a) and ecological monitoring areas (b)

Compared with some other agricultural areas, it was found that the content of heavy metals in the soil in the present study area tends to be lower. Specifically, the Pb, Cu and As concentrations in the Dhaka region in the soil were recorded about 41–87.5 mg/kg; 35.50–91 mg/kg; 32.50–80 mg/kg and 10.25–45 mg/kg, respectively (Bhuiyan *et al*. 2021). In another study by Giao and Dan (2020), Cu and Zn concentrations recorded in soil samples for rice, rice-shrimp and crop production in Bac Lieu province ranged from 16.79 to 32.67 mg/kg and 22.18–110.33 mg/kg, respectively. Similarly, the study of Ha *et al.* (2017) also showed that the average content of Cu and Zn in soil samples collected in agricultural models in Trac Van commune (Ha Nam) was higher than that of the current study, corresponding to 30.10±4.83 mg/kg and 88.73±8.43 mg/kg. In addition, in agricultural land in Kamfiruz district, the average concentrations of Cr, Cu, Zn and As determined were 89.85 mg/kg, 39.48 mg/kg, 126.36 mg/kg and 10.59 mg/kg (Rostami *et al*. 2021), higher than the current study area. The above studies showed that agricultural farming activities in Soc Trang province have not yet had a significant environmental impact. In general, the concentration of heavy metals Pb, Cu, Cr, Zn and As in agricultural soil in Soc Trang province in 2021 still showed no signs of pollution and is within the allowable limit of QCVN 03-MT:2015/BTNMT.

From the above analysis, the soil in the study area has an acidity in the range of moderate to neutral acidity. On average, the heavy metal content in the soil gradually decreased in the order Zn > Cr > Cu > Pb > As, with Zn present in the soil the highest. The brackish water ecological area has the highest concentration of Cu and Zn, followed by the freshwater area, which also appears to be the two heavy metals with the highest concentration, Pb and Cr. In comparison, the biological area has the highest concentration of Cu and Zn. In the saltwater state, only As appeared in the highest concentration. Compared with the standard, five heavy metals monitored at eight survey sites are still within the allowable threshold QCVN 03-MT:2015/BTNMT. However, the excessive use of fertilizers and pesticides is considered one of the causes contributing to the increase of heavy metals and pollution, mainly for arable land in several countries in Asia (Huong *et al.* 2012). In addition, the area also has shrimp farming activities, which generate manure, feed residue and water treatment chemicals, soil, disinfectants, biocides, herbicides, organic and inorganic fertilizers, feed additives and therapeutic drugs that will contribute to the formation and increase of heavy metals (Pathak *et al*. 2000, Zhang *et al*. 2012).

Correlation of heavy metals in soil

When analyzing the correlation between soil quality parameters, a close positive relationship was found between pH_{H2O}, pH_{KCl}, Zn and As (Table 2). Specifically, pH_{H2O} and pH_{KCl} have a high correlation coefficient of 0.988 at the $p < 0.01$ significance level. pH_{H2O} has a positive correlation coefficient with Zn and As of 0.788 and 0.826, respectively, correlated at 95% significance level. Similarly, pH_{KCl} is also correlated at 95% with Zn and As, with correlation coefficients of 0.808 and 0.756, respectively. Finally, the correlation analysis results indicated that there was a significant instrumental relationship between Zn and As with $r = 0.743$ at the $p < 0.05$ significance level. Another study by Shan *et al.* (2013) showed that the pH factor in the soil has very little correlation with heavy metals, which was similar to the study. In addition, according to the report of Bhuiyan *et al*. (2021), the results of correlation analysis showed that most of the observed heavy metals have a linear correlation with each other, such as Cu, Zn and Pb have a significant positive correlation, which represented the common origin of human activities.

Table 2. Correlation between soil quality parameters

Parameter	pH_{H2O}	pH_{KCl}	Pb	Cu	Cr	Zn	As
pH_{H2O}	1						
pH_{KCl}	0.988^{**}	1					
Pb	-0.40	-0.37	1				
Cu	-0.15	-0.21	0.03	1			
Cr	-0.38	-0.35	0.65	0.58	1		
Zn	0.788^{*}	0.808^{*}	-0.38	0.20	0.09	1	
As	0.826^{*}	0.756^{*}	-0.31	0.23	-0.07	0.743^{*}	1

Note: ** correlation at the level of significance $p < 0.01$; * correlation at the level of significance $p < 0.05$

Table 3 showed that there were at least 5 sources affecting soil quality in the study area, in which PC1 and PC2 are the main components, contributing significantly to the formation of heavy metals in soil with values eigenvalues greater than 1. A scree plot was used to show the eigenvalues of significant principal components (Fig. 3).

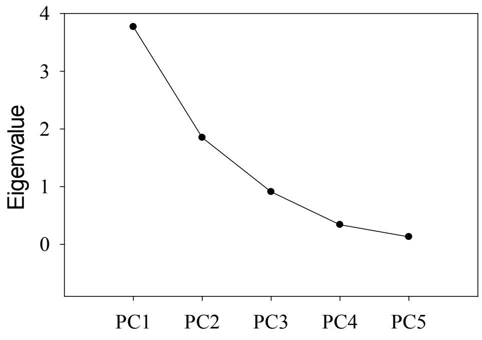

Fig. 3. Scree plots of PCA analysis

Table 3. Main factors affecting soil quality

Parameter	PC1	PC2	PC3	PC4	PC5
pH_{H2O}	-0.501	-0.001	-0.194	0.149	-0.284
pH_{KCl}	-0.492	0.011	-0.274	-0.061	-0.377
Pb	0.295	-0.284	-0.730	0.303	-0.237
Cu	0.042	-0.593	0.561	0.279	-0.498
Cr	0.204	-0.640	-0.200	-0.344	0.280

Parameter	PC1	PC2	PC3	PC4	PC5
Zn	-0.434	-0.300	-0.007	-0.602	0.050
As	-0.434	-0.263	0.007	0.569	0.626
Eigenvalue	3.77	1.85	0.91	0.34	0.13
% Var	53.90	26.40	13.00	4.90	1.90
% Cum. Var	53.90	80.20	93.20	98.10	99.90

Five PCs were formed, which explained 99.9% of the variation of the original data set, with 53.9%, 26.4%, 13%, 4.90% and 1.90%, respectively. Liu *et al.* (2003) classified the factor loads according to three levels as strong, moderate and weak, corresponding to absolute values greater than 0.75, 0.75–0.5 and from 0.5–0.3. Similarly, the results of the correlation analysis, PC1 with the contributions of pH_{H2O}, pH_{KCl}, Zn and As, were at a weak to moderate correlation. PC2 collected heavy metals Cu, Cr and Zn, with negative correlation coefficients of (-0.593), (-0.640) and (-0.300), respectively. PC3 exhibited a mean negative correlation with Pb (-0.730) and a positive correlation with Cu (0.561). PC4 aggregated most heavy metals Pb, Cr, Zn and As, ranging from weak to moderate correlation. Finally, PC5 appeared to have a positive correlation coefficient with As (0.626) at a medium level and a negative correlation with Cu (-0.498) at a weak level. As can be seen, PCAhad a more general view of the relationship between soil environmental parameters and the correlation mainly ranges from weak to moderate. The initially observed parameters all affect the change in soil quality in the study area. The analysis showed that Pb and Cr had at least two sources and Cu, Zn and As had at least three sources in the soil. The results of this analysis could help identify possible pollution sources in the study area. Using phosphate fertilizers, copper-based fungicides and insecticides has been reported to increase soil Pb, Cu and Cr concentrations; using calcium-based fertilizers increases Zn concentrations and uses more phosphate fertilizers. Herbicides have the ability to increase Cu in soil (Mng'ong'o *et al.* 2021). Insecticides containing the active ingredient Glyphosate are believed to be the source of heavy metals such as As, Cr, and Pb (Defarge *et al.* 2018). In addition, heavy metals such as Cu and Zn can be introduced into the soil from manure used in agriculture with estimated concentrations of 2-172 µg/g and 15-556 µg/g, respectively (Mico *et al.* 2006). Furthermore, input sludge for agriculture is also considered the source of Zn formation in soil (Srivastava *et al.* 2017). Thus, the area with the cultivation of rice, vegetables and fruit trees, mainly in the area, uses a lot of plant protection chemicals, which can be the source of formation and increase of heavy metal concentrations in the soil.

Clustering soil quality basing heavy metal concentrations

In order to find the monitoring locations with similar soil characteristics, cluster analysis (CA) was performed (Fig. 4). CA results from eight soil samples have formed two large soil groups, with group I including D1, D2, D3, D4 and group II including D5, D6, D7, D8. As can be seen, these two groups represent brackish, saline and freshwater ecological areas. Also, to have a closer look at the soil groups (orange line), with five soil groups formed. In which, group I (D2), with the highest presence of As (10.90 mg/kg) and the lowest Pb (8.54 mg/kg) among the groups. Group II includes D1, D3 and D4, with soil with neutral acidity (pH_{H2O} 7.19 and pH_{KCl} 6.96) and Zn content (78.07 mg/kg) in the highest soil. Next, group III represents a distinct site (D6), where the soil is highly acidic (pH_{H2O} 4.18 and pH_{KCl} 4.05), leading to most of the heavy metal content in the soil being low such as Cu, Zn and As. Similarly, group IV also represents a separate site, D5, with the highest Cu and Cr content of the five soil groups. Finally, group VI assembled two sites, D7 and D8, with the highest Zn presence. It can be seen that the acidity and heavy metals present in the soil have made a significant difference between the soil groups in the study area. CA has also been successfully applied in many studies by Micó *et al.* (2006), Bhuiyan *et al.* (2010) and Khan *et al.* (2011) to classify soil quality.

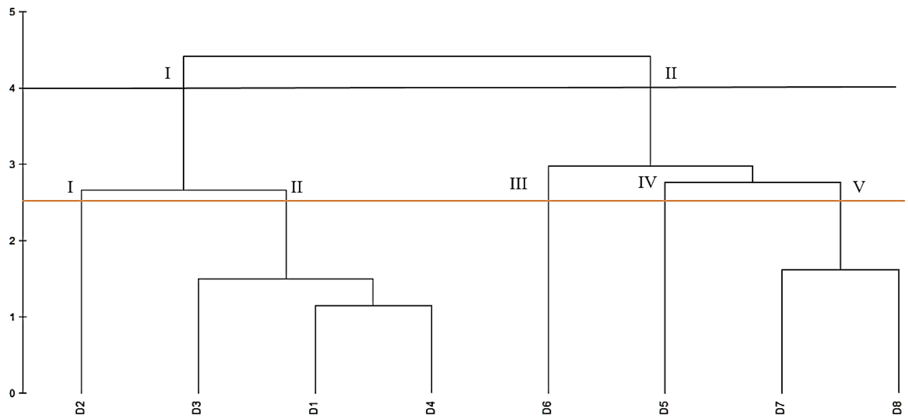

Fig. 4. Results of soil quality grouping using CA

Ecological risk of heavy metals in agricultural soil

Heavy metals, if present in large amounts in the soil, can pose many potential risks to the ecosystem. The ecological risk index (RI) provides a quantitative value for the aggregate pollution risk for a particular ecological system based on the toxicity of heavy metals and their response to the environment (Musa *et* *al*. 2017). In the study, RI was performed to assess the potential ecological risk due to the presence of five heavy metals, Pb, Cu, Cr, Zn and As. Table 4 showed that the average single ecological risk coefficient (E^i_r) of heavy metals gradually increases from Zn < Cu < Pb < Cr < As, with coefficients of variation of 0.99–1.82, 5.54–7.10, 2.85–10, 12.12–22.76 and 7.11–59.47, respectively. The results also confirmed that As and Cr have high single-risk values, indicating that this element can pose a great risk to the environment and humans if not strictly controlled (Wu *et al*. 2016, Khan *et al*. 2010). The RI values at eight monitoring locations ranged from 33.71 to 91.04, averaging 68.84. According to the risk rating scale of Hakanson (1980), the results reflect a low level of ecological risk, similar to some other studies by Du *et al.* (2014) and Rostami *et al.* (2021). However, in the survey locations, D4 is the location that creates the highest potential ecological risk, which can be explained as the area where fruit trees are grown using many input chemicals containing heavy metals, leading to high concentrations of heavy metals in the soil of this cropping area, creating a major ecological risk. Therefore, it is necessary to continue monitoring soil quality and control pollution sources that can form heavy metals in the soil. Moreover, more research on the ecological risk index in agricultural land is needed to form a basis for sustainable agricultural management and land use.

Table 4. Estimated ecological risk due to heavy metal concentrations

Sites	E^i_r Pb	E^i_r Cu	E^i_r Cr	E^i_r Zn	E^i_r As	RI
D1	6.30	7.03	17.12	182	46.32	78.58
D2	2.85	7.03	12.18	1.55	57.37	80.97
D3	6.17	5.54	12.12	1.51	40.05	65.39
D4	7.27	6.50	16.18	1.63	59.47	91.04
D5	7.60	7.10	22.76	1.60	40.89	79.96
D6	5.23	6.29	13.94	1.14	7.11	33.71
D7	7.83	6.57	15.00	0.99	32.58	62.98
D8	10.00	6.80	19.00	1.05	21.21	58.06
Mean	6.66	6.61	16.04	1.41	38.13	68.84

CONCLUSIONS

The content of heavy metals Pb, Cu, Cr, Zn and As in the agricultural soil of the study area has not shown any signs of pollution and was still within the allowable limits QCVN 03-MT:2015/BTNMT with metal levels. The heavy metals in the soil gradually increased in the order As < Pb < Cu < Cr < Zn and Zn had the highest concentration of the five surveyed heavy metals. Soils with moderate to neutral acidity are reflected in pH_{H2O} and pH_{KCl} values. The Pearson and PCA analysis results showed that the soil quality parameters had a weak to moderate correlation, Pb and Cr had at least two sources of pollution and Cu, Zn and As had at least three pollution sources in the soil, possibly coming from human agricultural activities. CA analysis has formed two large groups of soil quality belonging to ecological areas (brackish, saline) and fresh from the difference between soil environmental parameters. The RI index ranged from 33.71 to 91.04, representing a low level of potential ecological risk in the study area. In addition, the single ecological risk coefficient indicated that As and Cr had a great potential impact on the environment and humans. It is necessary to limit the sources of As and Cr generation into the environment and orient sustainable farming in agriculture. In the future, it is necessary to continue monitoring and evaluating ecological and health risks due to heavy metals appearing in the soil in the study area.

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