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Assessment of Occurrence, Ecological and Health Risk of Heavy Metals in Agricultural Soil in the Hau Giang Province, Vietnam

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ABSTRACT

The study aimed to evaluate the occurrence of some heavy metals in agricultural soil in the Hau Giang province, Vietnam. The geographical accumulation index (Igeo), pollutant load index (PLI) and ecological risk index (RI) are used to assess the pollution levels and potential ecological risks due to the presence of heavy metals in agricultural soil. The results showed that the mean concentrations of Cu, Pb and Zn in the soil ranged from 16.25–40.32, 18.05–29.92 and 52.78–147.22 mg/kg, respectively, within the limits of QCVN 03-MT:2015/BTNMT. Cluster analysis showed that Pb originated from the process of using fertilizers, especially phosphate fertilizers in farming. Cu and Zn possibly share a common origin from the use of pesticides and fungicides in agricultural production. The Igeo value of Cu, Pb and Zn gradually increases in the order of Cu < Zn < Pb. The PLI (1.03–1.97) reflected that the soil in the study area is moderately polluted. The RI (14.80–25.33) represented a low potential ecological risk. In particular, position D3 had the highest level of pollution and risk among the study sites. Pb had the highest level of accumulation in soil with the highest single ecological risk factor; thus, measures should be taken to limit the source of Pb generation. The results of the study also indicated that ingestion route is the main exposure pathway by which heavy metals can be harmful to humans.

Keywords: agricultural soil, ecological risks, health risks, Hau Giang province.

INTRODUCTION

Soil contamination by heavy metal accumulation has become a global problem, because of the potential threat to food safety and potential impact on human health by the food chain (Jiwan et al., 2011; Simon et al., 2016; Oumenskoul et al., 2018). Heavy metals have toxic effects on soil microorganisms, altering the diversity, population size and overall activity of the soil microbial community such as respiration rate, enzyme activity, from which degrades soil quality (Ashraf and Ali, 2007). The plants that absorb heavy metals from the soil at high concentrations can lead to huge health risks when it comes to food chain impacts. Plant root uptake is one of the main pathways leading to the entry of heavy metals in the food chain, which is a potential threat to human health, severely depletes a number of essential nutrients in the body, causing impaired immunity and cancer (Jordão et al., 2006). Cadmium (Cd) has been determined to be toxic to the liver, placenta, kidneys, lungs, brain, and bones, especially if heavy exposure to Cd can lead to pulmonary edema and death (Thévenod and Lee, 2013; Sarkar et al., 2013; Genchi et al., 2020). Zinc (Zn) is considered relatively non-toxic; however, high accumulation of Zn in the body can cause systemic dysfunction leading to impaired growth and reproduction, and in humans, Zn often accumulates mainly in the liver (Dan and Tho, 2011; Pandey et al., 2016). High intake of Cu can lead to severe mucosal irritation and corrosion, damage to capillaries, liver, kidneys, and central nervous system irritation, leading to depression (Alengebawy et al., 2021). In turn, 1g Cu/kg body weight can lead to death (Dan and Tho, 2011). Lead (Pb) is the leading toxic heavy metal even at extremely low concentrations (Paydey et al., 2016; Alengebawy et al., 2021). Acute Pb poisoning can lead to dysfunction of the kidneys, reproductive system, liver and brain leading to serious illness and death. Therefore, the cultivation of food crops and vegetables on soil contaminated with heavy metals is a great potential risk, because plant tissues accumulate heavy metals.

The risk of human exposure to heavy metals through food increases when food is grown on the soil contaminated with heavy metals (Simon et al., 2016). Agricultural land can be contaminated with heavy metals through activities, e.g. irrigation of contaminated water and the use of agrochemicals containing heavy metals such as pesticides, herbicides, municipal waste used for fertilizing and even mineral fertilizers containing traces of heavy metals (Onakpa et al., 2018). Therefore, monitoring the concentration of heavy metals in the soil becomes very important. Indices such as geographical accumulation index (Igeo), pollutant load index (PLI), ecological risk index (RI), exposure index (CDI), hazard index (HI) of non-carcinogenic and carcinogenic substances are widely used to assess pollution levels, environmental risks, as well as the health risks due to heavy metal presence in soil (Mugai et al., 2016; Oumenskoul et al., 2018; Baltas et al., 2019; Al-Taani et al., 2021). The Hau Giang province is located in the Mekong Delta, has a mild climate, favorable natural conditions and soil, and has rich and diverse potentials in agricultural development such as specializing in rice cultivation, intercropping with rice-upland crop, fruit trees (Giang, 2021). However, in the cultivation process, the use of many pesticides can increase the content of heavy metals in the soil, adversely affecting the environment and human health. In addition, there are currently no studies to assess the heavy metal pollution in agricultural land in the Hau Giang province affected by different agricultural farming models. Considering the above-mentioned issues, the study to assess the environmental impacts and human health risks due to the presence of some heavy metals (Cu, Pb, Zn) in agricultural land in the Hau Giang province was carried out. The research results can assess which heavy metals pose the most risk, thereby proposing the measures to limit the generation, reduce the possibility of ecosystem pollution, especially human health.

MATERIALS AND METHODS

Study area

The Hau Giang province has a natural land area of 1621.7 km^2 (162,223 ha), accounting for about 4% of the area of the Mekong Delta and about 0.4% of the total natural area of the country. The topography of the province is divided into three characteristic regions. The tidal zone is the area bordering the Hau River with an area of 19,200 ha, strongly developing the garden economy, agriculture, forestry and fishery economy. The intertidal zone is adjacent to the intertidal zone with an area of about 16,800 ha, strongly developing rice. The flooded areas develop diversified agriculture such as rice, sugarcane, and pineapple. It can be seen that the agriculture in the region is highly developed and accounts for a large proportion. Every year, farmers in the province have to use a large amount of pesticides in their production (Farmers Association, 2014). According to a report from the Plant Protection Sub-Department of Hau Giang Province, on average, the province generates about 5–7 tons of waste from pesticides every year.

Soil sampling and analysis

Soil samples were assessed in four types of agricultural cultivation as follows: (1) D1: Rice soil in Vinh Thanh Dong commune; (2) D2: Area of land for intercropping of rice – upland crops – aquatic products in Vi Binh commune; (3) D3: Soil for growing pomelo in Phu Huu commune; (4) D4: Soil for pineapple cultivation in Hoa Tien commune. The content of Cu, Pb, Zn was analyzed by using the atomic absorption method (AAS) at the laboratory of the Center for Natural Resources and Environment Monitoring of Hau Giang province according to the standard methods (APHA, 1998).

Data analysis

The contents of Cu, Pb, and Zn were compared with QCVN 03-MT:2015/BTNMT – Agricultural Soil. The relationship and origin of heavy metals formation as well as soil quality subgroups between sites were also performed through cluster analysis (Mungai et al., 2016).

Using pollution indicators is an effective tool to assess anthropogenic soil pollution

(Oumenskoul et al., 2018). Igeo is calculated based on the metal content in the soil. PLI was also used to assess the extent of this contamination and the RI was used to assess the potential ecological risk. In this study, it is necessary to know the heavy metal values in the geochemical background. The formula for calculating pollution and risk indices is as follows:

- Geoaccumulation Index (I_{geo}):

$$I_{geo} = \log_2 [\frac{Cn}{1.5GB}] \tag{1}$$

- Pollution Load Index (PLI):

$$PLI = \sqrt[n]{PI_1 \ x \ PI_2 \ x \ PI_3 \ x \ \dots PIn} \tag{2}$$

- Potential ecological risk (RI):

$$RI = \sum_{i=1}^{n} E_r^i = \sum_{i=1}^{n} T_r^i \ x \ PI \tag{3}$$

where: Cn is the concentration of heavy metal measured in the soil sample; Gn is the geochemical background value in the soil, Cu, Pb and Zn have background values of 55, 12.5 and 70, respectively (Baltas et al., 2019); 1.5 factor to reduce the effect of possible variations in the subsoil and anthropogenic effects; n is the quantity of heavy metals observed; PI is the pollution index of each metal; Eir is a single potential risk index; T^i_r is the metal toxicity coefficient provided by Hakanson (1980), Cu = Pb = 5, Zn = 1. The rating of pollution and ecological risks is presented in Table 1.

The assessment of health risks from heavy metals through analysis of exposure and risk of non-carcinogenic substances is as follows:

Exposure analysis: soil heavy metal exposure is characterized by chronic daily intake (CDI, mg/kg/day). To estimate direct soil exposure, three exposure pathways are considered, including inhalation, dermal, and ingestion. CDI in the three exposure pathways was calculated using the following equations (Eziz et al., 2018; Baltas et al., 2019):

$$\begin{aligned} \text{CDI ingestion} = {} & [(\text{Ci} \times \text{IngR} \times \\ & \times \text{FC x EF} \times \text{ED})/\,(\text{BW} \times \text{AT})] \end{aligned} \tag{4}$$

$$\begin{aligned} \text{CDI inhalation} = {} & [(\text{Ci} \times \text{InhR} \times \\ & \times \text{EF} \times \text{ED})\,/\,(\text{PEF} \times \text{BW} \times \text{AT})] \end{aligned} \tag{5}$$

$$\begin{aligned} \text{CDI dermal} = {} & [(\text{Ci} \times \text{SA} \times \text{AF} \times \text{ABS} \\ & \times \text{EF} \times \text{ED} \times \text{FC})\,/\,(\text{BW} \times \text{AT})] \end{aligned} \tag{6}$$

$$\begin{aligned} \text{CDI total} = {} & \text{CDI ingestion} + \\ & + \text{CDI inhalation} + \text{CDI dermal} \end{aligned}$$

where: Ci is the concentration of each heavy metal (mg/kg); IngR indicates the rate of exposure (mg/day), EF indicates the frequency of exposure (day/year); ED

Table 1. Pollution and ecological risk index rating scale (Barbieri, 2016; Mungai et al., 2016; Adimalla et al., 2019)

Index	Value	Rating scale	Index	Value	Rating scale
Igeo	Igeo ≤ 0	No pollution	E^i_r	$E^i_r < 40$	Low
	0 < Igeo < 1	No to moderate		$40 \leq E^i_r < 8$	Moderate
	1 < Igeo < 2	Moderate		$80 \leq E^i_r < 160$	High
	2 < Igeo < 3	Moderate to high		$160 \leq E^i_r < 320$	Very high
	3 < Igeo < 4	High		$E^i_r \geq 320$	Extremely high
	4 < Igeo < 5	High to very high			
	Igeo ≥ 5	Extreme pollution			
PLI	PLI < 0	No pollution	RI	RI < 150	Low
	1 < PLI < 2	Moderate		150 ≤ RI < 300	Moderate
	2 < PLI < 3	High		300 ≤ RI < 600	High
	PLI >3	Extremely high		RI ≥ 600	Very high

Table 2. Exposure parameters for estimating CDI

Variables	IngR	InhR	FC	EF	ED	SA	AF	ABS	PEF	BW	AT
Adult	100	20	10^{-6}	350	24	1530	0.49	0.001	1.36×10^9	56.8	ED×365
Child	200	7.65	10^{-6}	350	6	860	0.65	0.001	1.36×10^9	15.9	ED×365

Table 3. RfD for non-carcinogenic metals

Metal	RfD		
	Ingestion	Inhalation	Dermal
Cu	0.04	0.04	0.012
Pb	0.0035	0.00352	0.000525
Zn	0.3	0.3	0.06

is exposure time (years), BW is mean body weight (kg); AT is the average time (days); FC is the conversion factor; InhR indicates the intake rate (m^3/day); PEF is the particle emission factor; SA is the contact surface area (cm^2); AF is soil adhesion coefficient (mg/cm^2); ABS indicates the absorption coefficient through the skin. The exposure variables for estimating CDI is showed in Table 2.

The single non-carcinogenic potential hazard of heavy metals is calculated by the equation:

$$\mathrm{HQ} = \mathrm{CDI\ total} / \mathrm{RfD} \tag{7}$$

where: RfD displays the reference dose (mg/kg/day or mg/m^3) as in Table 3. Regarding the assessment of overall health risks posed by all heavy metals, the HQ value of the metal is aggregated and expressed as the hazard index (HI):

$$\mathrm{HI} = \mathrm{HQ\ ingestion} + \mathrm{HQ\ inhalation} + \\ + \mathrm{HQ\ dermal} \tag{8}$$

RESULTS AND DISCUSSION

Heavy metal content in soil in the period of 2019–2021

The Cu content at each location in the period of 2019–2021 is shown in Figure 1a. At positions D1 and D3, the Cu content tends to increase gradually from the period 2019–2020 and gradually decrease from the period 2020–2021 with values ranging from 12.60–29.80 and 19.50–61.30 mg/kg, respectively. The remaining two positions D2 and D4, Cu increased gradually over the years with concentrations ranging from 11.10–45.30 and 5.30–24.55 mg/kg. Through the analysis, the three-year average Cu observed was lowest at D4 and highest at D3 with the values ranging from 16.25–40.32 mg/kg. It can be seen that position D3 in a pomelo growing area produces the highest Cu content. The use of large amounts of fertilizers, pesticides, fungicides over a long period of time, the frequency of spraying per crop can be 24 times or more for citrus crops, contributing to an increase in the concentrations of heavy metals in soil (Kelepertzis, 2014; Adami et al., 2019). However, the Cu content in the soil of the study area is still within the allowable limit QCVN 03-MT:2015/BTNMT – Agricultural soil (Cu=100 mg/kg). In another study, the Cu concentration in Shizhuyuan and Banqiao areas was quite high, with 109.24 mg/kg and 135.83 mg/kg, respectively (He et al., 2020). However, compared with the agricultural cultivation area in Liwa, Abu Dhabi, the Cu concentration in this area is relatively low, ranging from 10.29–21.7 mg/kg with an average of 14.17 ± 2.68 mg/kg (Al-Taani et al., 2021). Similarly, the Cu concentration in agricultural soils in Kenya and Eastern Africa is very low with an average of 5.05±13.42 mg/kg (Mungai et al., 2016). High rates of Cu fusion in soil are often caused by the use of Cu-based fungicides or other agricultural activities, and the range of Cu concentrations in farmland is from 5–30 mg/kg, but these levels depend on conditions and geographical location (Alengebawy et al., 2021).

For lead, the Pb content tends to increase gradually over the years from 2019–2021 at positions D1, D2, D3 and position D4 in particular, has a decreasing trend from the period 2019–2020 and continues to increase in 2021 (Figure 1b). The Pb concentrations at each position D1, D2, D3 and D4 ranged from 14.40–51.45, 18.90–46.25, 17.50–47.25 and 11–28.75 mg/kg, respectively with the mean value from 18.05 to 29.92 mg/kg. Through the average value, it can be seen that in the D1 area, intensive rice cultivation has the highest Pb content in the soil. At the same time, the process of agricultural cultivation has contributed to the formation of the Pb concentration in the soil as Pb continuously increases over the years. The soil with high organic matter content will lead to higher soil Pb content than soil with low organic matter (Giao and Dan, 2020). Besides, the only form of lead in ionic forms is the stable oxidation state Pb^{2+}, which will form very stable biotoxic compounds (Pandey et al., 2016). According to Ha (2012), the lead content in agricultural soils fluctuated considerably from 24.25–948.77 mg/kg, higher than the current study area and lead in mobile form is easily absorbed by plants. Therefore, the higher the concentration of mobile lead in the soil, the greater the toxicity to plants and the environment. In addition, according to Huong (2014), the Pb content in agricultural soil is quite high and is thought to be affected by contaminated irrigation water. In some agricultural production areas in Da Nang city, the Pb concentration is relatively lower than in the present study area, only ranging from 2.08±1.5–3.58±2.00 mg/kg (Cuong et al., 2014). In general, the Pb content in soil of the Hau Giang province is still within the allowable limit QCVN 03-MT:2015/BTNMT – Agricultural soil (70 mg/kg).

The Zn content in the soil was relatively high, but still within the allowable limits QCVN 03-MT:2015/BTNMT – Agricultural land (200 mg/kg) (Figure 1c). In particular, at position D3, the Zn content is highest and increases gradually over the years of pomelo cultivation. In 2021 alone, the Zn content was about to reach the limit with 194.25 mg/kg. According to the study Giao and Dan (2020), the Zn content in the soil is also quite high, ranging from 22.18–110.33 mg/kg, which may be affected by industrial production activities and excessive use of fertilizers in farming processes. In addition, zinc can enter the soil environment from agricultural wastes, sewage sludge. The Zn^{2+} form is a toxic form capable of forming very stable biotoxic compounds (Pandey et al., 2016). In the agricultural farming area north of Telangane, India, the Zn content is also quite high, ranging from 71.3–173 mg/kg (Adimalla et al., 2019). Compared with the Liwa cultivation area, the Zn content was relatively low, ranging from 42.39–66.92 mg/kg with an average of 54.08 mg/kg (Al-Taani et al., 2021). Thus, it can be seen that the process of agricultural cultivation has contributed to the increase of the Zn content in the soil in the study area.

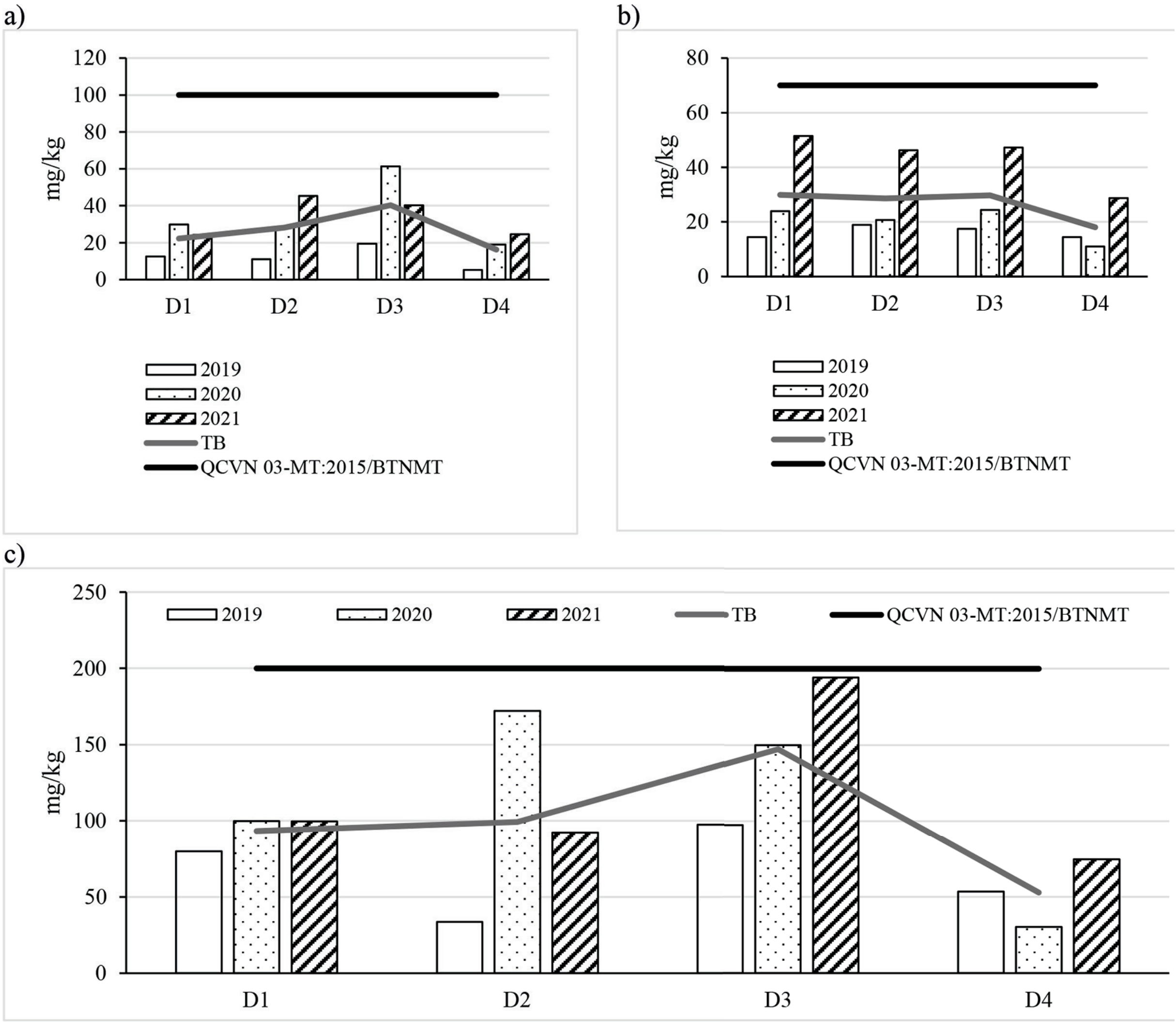

Figure 1. a) Cu content, b) Pb content, c) Zn content in soil at each location in the period 2019–2021

The results showed that, on average, the concentration of heavy metals gradually increased from Pb < Cu < Zn and at position D3, the pomelo cultivation area had the highest concentration of heavy metals in the soil and tended to gradually increased over the years. From there, it was proven that this citrus tree planting is contributing to the formation of heavy metals, affecting the quality of soil in the study area. Physical and chemical properties, soil pH, aeration, humus content all affect the existence of heavy metals. In addition, tillage techniques and plant varieties also directly affect the heavy metal content in the soil. Especially, the selection of plant varieties with high heavy metal absorption capacity will reduce the amount of heavy metals in the soil (Cuong et al., 2014).

Relationship between heavy metals in soil in the period of 2019–2021

Cluster analysis is commonly used to measure the correlation between concentrations of heavy metals and provides the information indicating heavy metal origins (Zhou et al., 2014). Figure 2 shows the process of heavy metal clustering in the soil. From the data of three heavy metals surveyed in the study area, CA analysis formed two heavy metal groups. Group I showed that the Pb content was different from the Cu and Zn content in the soil, and also had different formation origins. Meanwhile, Cu and Zn in the same group (group II) show that they share a common origin. Pb can arise from lead contaminated irrigation

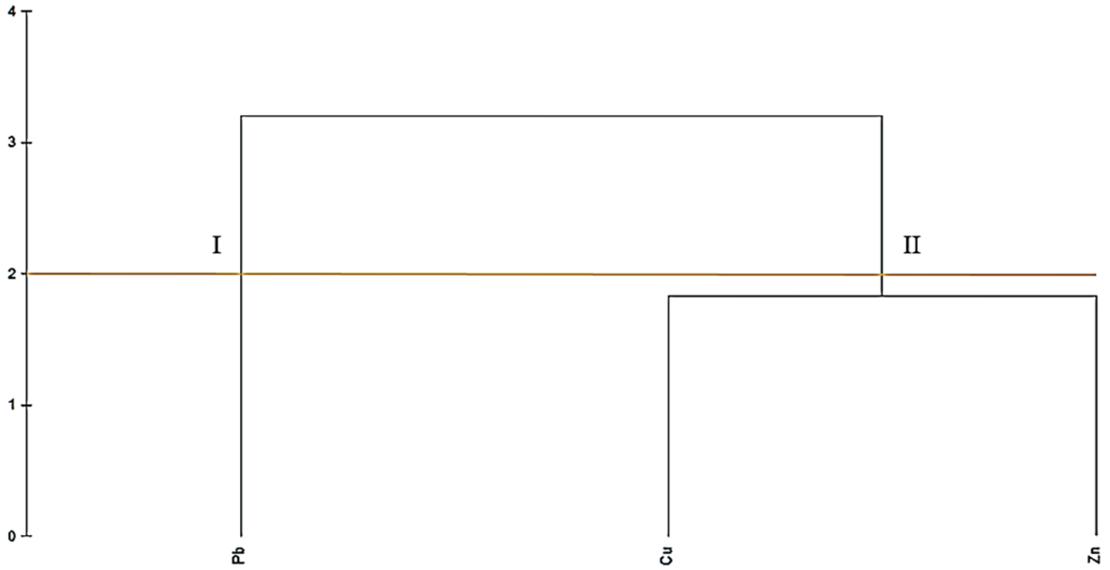

Figure 2. Classification of heavy metals in soil

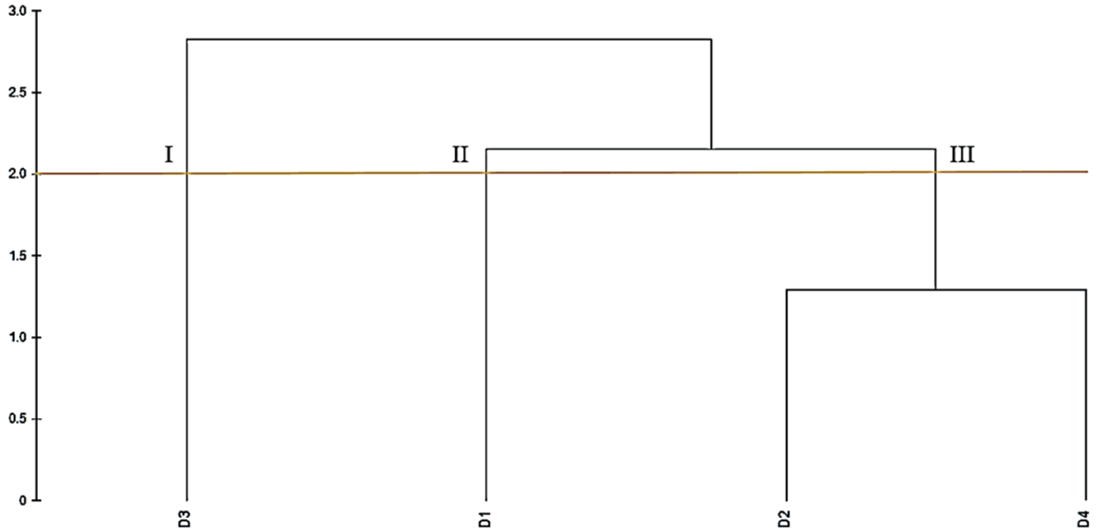

Figure 3. Clustering soil quality based on heavy metals

water, overuse of fertilizers, mainly phosphate and organic fertilizers (Zhang, 2006; Hani and Pazira, 2011; Extracted from Zhou et al., 2014; Marrugo-Negrete et al., 2017). Cu and Zn can be formed from fertilizers, pesticides and fungicides used in farming (Marrugo-Negrete et al., 2017).

Similarly, the sampling sites were also subjected to cluster analysis to identify sites with similar soil quality based on the heavy metal content (Marrugo-Negrete et al., 2017; Esmaeilzadeh et al., 2018). The analysis results show that there are three soil quality groups formed (Figure 3) with group I and group II consisting of a separate location corresponding to D3 and D1, and group III consisting of two positions D2 and D4. The results also showed that the position D3 had the highest concentration of heavy metals in the soil.

Assessment of the environmental impact of heavy metals in agricultural soils

The geographical accumulation index (Igeo) is used to assess the heavy metal pollution in agricultural land. Igeo values of Cu, Pb and Zn ranged from (-1.77)–(-0.86), 0.62–1.46 and (-0.49)–0.89, the average value with (-1.36), 1.18 and 0.03 respectively (Table 4). The data from Table 4 proves that Cu at the unpolluted level (Igeo < 0), Zn at the unpolluted level (Igeo < 0) accounted for 75% of the soil sample and non-polluted to slightly contaminated (0 < Igeo < 1) accounted for 25%. In the observed soil samples, Pb had the highest pollution level with 75% of the soil samples having the average pollution level (1 < Igeo < 2). Average results Igeo increase in order Igeo Cu < Igeo Zn < Igeo Pb. Similar to the study Esmaeizadeh et al. (2018), the Igeo levels were also highest at heavy metal Pb with 1.95 in the mean range. The results of the study are different from those reported by Marrugo-negrete et al. (2017), with Igeo Zn and Cu values at moderate to severe contamination (2 < Igeo < 3) and Pb at moderate contamination (1 < Igeo < 2). In addition, in another study, the Igeo value indicated that Cu, Pb and Zn were all at pollution-free levels (Baltas et al., 2019). This shows that depending on the observed heavy metal content at each location, area as well as selected background value, the geographical index of heavy metal accumulation in the soil is different. The research results show that the agricultural land in the Hau Giang province shows signs of being polluted by Pb.

The Pollution Load Index (PLI) is used to determine multi-metal contamination, calculated for every sampling site. The PLI value of the soil in the study area ranged from 1.03 to 1.97, representing a moderate level of pollution (Figure 4). And at position D3, the pomelo growing area has the highest pollution level, which is similar to the high concentration of heavy metals in the soil as previously analyzed, which can cause high potential risks to the ecosystem. Similarly, the Neyshabur Plain agricultural crop is also moderately polluted with the mean PLI value for all the heavy metals studied being 1.75 (Esmaeizadeh et al., 2018). In the agricultural farming area of Telangana, the pollutant load index ranges from 0.86 to 1.97, with 13% of the soil samples being unpolluted and up to 87% of the soil samples being moderately contaminated by heavy metals in the soil (Adimalla et al., 2019). In the research by Khalifa & Gad (2018), it was reported that the PLI values for agricultural topsoil samples ranged from 2.29–3.89 with high pollution, more polluted than the present study area. As reported by Oumenskou et al. (2018), in the Beni Amir belt, due to the impact of agriculture and human activities, the PLI values higher than 1 accounted for 74.5% of contaminated soil samples, indicating the problem of metal pollution and the serious deterioration of soil quality. Thus, it can be concluded that agricultural farming activities in the study area have significantly polluted the soil environment.

The potential ecological risk posed by heavy metals in the soil was assessed using the potential ecological risk index (RI). The degree of individual potential ecological risk of each heavy metal in agricultural soil gradually increases in

Table 4. Igeo coefficient of heavy metals in soil

Sites	Igeo Cu	Igeo Pb	Igeo Zn
D1	-1.77	1.46	-0.08
D2	-0.86	1.30	-0.19
D3	-1.04	1.33	0.89
D4	-1.75	0.62	-0.49
Mean	-1.36	1.18	0.03

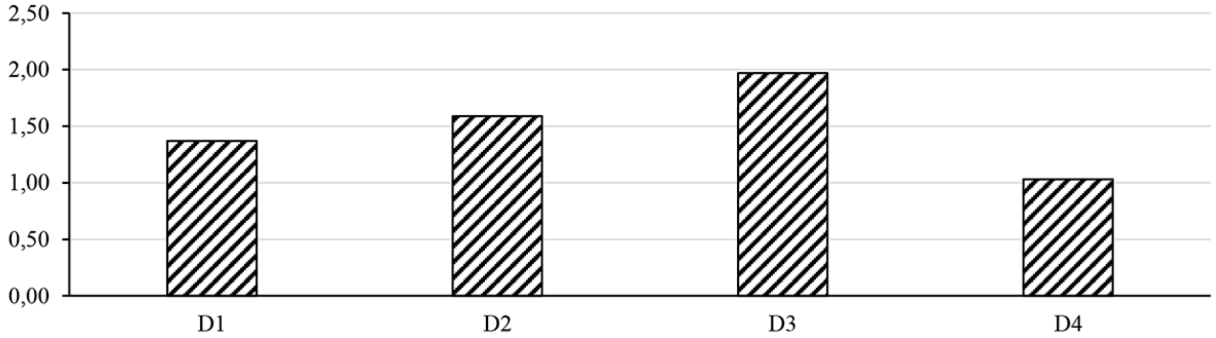

Figure 4. Pollution load index (PLI)

the order of Zn < Cu < Pb, with Zn, Cu, and Pb values ranging from 1.07–2.78, 2.20–4.12, and 11.50–20.58, reaching an average of 1.64, 3.05 and 17.37, respectively (Table 5). The ecological risk levels of the three heavy metals in arable soils range from 14.80–25.33 with an average risk factor of about 22.06. This indicates that the level of ecological risk due to the presence of three heavy metals Cu, Pb and Zn in the soil of the study area is still low. However, Pb has a high single risk factor, which indicates that this element can pose a great risk to the environment and humans if it not closely monitored. At the same time, the high ecological risk coefficient at location D3 - pomelo cultivation area will lead to the risk of accumulation of heavy metals as well as pesticide residues in agricultural products affecting human health (Table 5). Many studies have demonstrated that a substantial amount of heavy metals and pesticide residues were found on this citrus (Raja et al., 2016; Al-Nasir et al., 2020). Similarly, with the presence of some heavy metals in agricultural arable land in Kenya, the ecological risk coefficient for this area is also very low, ranging from 0.01 to 10.39 (Mungai et al., 2016). In another area, it is reported that the potential ecological risk is quite high, higher than the current study area with values ranging from 33.48–374.20 with 88.24% of low risk, 11.47% of moderate risk and 0.29% of significant risk (Ren et al., 2019). Some studies also show that the potential ecological risk in the study area is still lower than in other agricultural areas (Du et al., 2014; Zhang et al., 2019). In summary, the presence of heavy metals in the soil of the study area does not pose a major risk to the environment.

Assessment of health risks due to heavy metal presence in agricultural soils

From Table 6, it can be seen that the total non-carcinogenic daily intake (total CDI) of Zn for adults and children is the highest, with the values of 0.000196 mg/kg/day and 0.001393 mg/kg/day, respectively. The total CDI of Cu for adults and children was 0.000057 mg/kg/day and 0.000406 mg/kg/day, respectively, with the lowest total daily intake of the non-carcinogen. The total CDI level of three heavy metals in agricultural soil tends to increase gradually from Cu < Pb < Zn. The results also show that the total daily intake of non-carcinogenic substances is higher in children than in adults. The oral exposure for adults and children was the highest of the three exposure pathways. This result is consistent with the reports of other studies (Wei et al., 2015; Eziz et al., 2018; Baltas et al., 2019).

When examining the HQ values for non-carcinogenic risk, the values were higher in children than in adults (Table 7). Specifically, the HQ values for adults were only between 0.000672–0.021996, while the HQ values for children were found in

Table 5. Single and combined ecological risk coefficients for heavy metals in soil

Sites	E^i_r Cu	E^i_r Pb	E^i_r Zn	RI
D1	2.20	20.58	1.42	24.20
D2	4.12	18.50	1.32	23.93
D3	3.65	18.90	2.78	25.33
D4	2.23	11.50	1.07	14.80
Mean	3.05	17.37	1.64	22.06

Table 6. Daily exposure to the non-carcinogenic risk of heavy metals

Metal	CDI ingestion		CDI inhalation		CDI dermal		CDI total	
	Adult	Child	Adult	Child	Adult	Child	Adult	Child
Cu	5.66395E-05	0.000405	8.32934E-09	1.1381E-08	0.0000004	0.0000011	0.000057	0.000406
Pb	7.33106E-05	0.000524	1.0781E-08	1.4731E-08	0.0000005	0.0000015	0.000074	0.000525
Zn	0.000194376	0.001389	2.85848E-08	3.9059E-08	0.0000015	0.0000039	0.000196	0.001393

Table 7. Non-carcinogenic risk index of heavy metals in soil of cultivated area

Metal	HQ ingestion		HQ inhalation		HQ dermal		HQ	
	Adult	Child	Adult	Child	Adult	Child	Adult	Child
Cu	0.001416	0.010117	2.08233E-07	2.8453E-07	3.53855E-05	9.42543E-05	0.001452	0.010211
Pb	0.020946	0.149651	3.06278E-06	4.185E-06	0.001046875	0.002788498	0.021996	0.152444
Zn	0.000648	0.004629	9.52826E-08	1.302E-07	2.42873E-05	6.46927E-05	0.000672	0.004694
HI	Adult				Child			
	0.024				0.167			

the range of 0.0044694–0.152444, which was 6.65–6.93 times higher. The order of the HQ value of heavy metals increases from Cu < Zn < Pb. The results also show that the oral route for both children and humans is the main route by which heavy metals can damage human health. The HI values in adults and children were 0.024 and 0.167, respectively. According to the HI rating scale, it can be concluded that the heavy metals present in the arable land of the study area are not expected to have serious health effects; the risk may still exist, albeit incomputable (USEPA, 2001; Giao, 2020).

CONCLUSIONS

Concentrations of Cu, Pb and Zn in the soil of the study area for the period of 2019–2021 are still within the allowable limits of QCVN 03-MT:2015/BTNMT. In particular, in 2021 at position D3, the Zn content appears near the specified threshold. Analysis of heavy metal clusters indicated that the formation of two metal groups with the origin of Pb formation mainly from the abuse of phosphate fertilizers in farming, and Cu and Zn mainly come from the use of fertilizer, pesticides, fungicides and fungicides. The results of soil quality analysis formed three soil groups D3, D1, D2 and D4. D3 is the location with the highest concentration of heavy metals in the soil. Assessment of the level of pollution and environmental risks due to the occurrence of soil metals in the soil showed that Pb had the highest pollution level among the three surveyed heavy metals with 75% of soil samples are moderately polluted (1 < Igeo < 2). The PLI value ranged from 1.03–1.97, representing a moderate level of pollution due to heavy metals appearing in the soil. The RI values ranged from 14.80–25.33, indicating low ecological risk. The results also indicated that pomelo cultivation area (D3) has the greatest potential risk with higher heavy metal content in soil than other agricultural cultivation locations. The health risks due to the content of three heavy metals in soil in 2021 indicated that children are more vulnerable to non-carcinogenic substances than adults. Therefore, it is necessary to regularly monitor and monitor soil quality and orient sustainable agricultural cultivation.

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