Ecological Risk Assessment for Heavy Metals Occurrence in Rice Cultivation Areas in An Giang Province, Vietnam

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Abstract—**The study was conducted to assess the occurrence and ecological risk of heavy metal concentrations (Cu, Zn, Pb, Cd and As) in the soil of paddy fields in An Giang province in 2020. Soil samples were collected at 112 locations in seven paddy fields. Cluster analysis (CA) was used to present the spatial distribution of heavy metals. Ecological potential risk index (RI) was used to determine risk levels caused by heavy metals. The results showed that Cu, Zn, Pb and As in all soil samples ranging from 1.83-124.04, 4.87-114.18, 7.87-39.22 and 4.66-16.32 mg/kg, respectively. Cd was not detected in the soil samples. All heavy metal values were within the allowable limits of Vietnamese technical regulation on heavy metals in the soils. However, Cu concentration at the rice area in An Hoa hamlet, Khanh An commune, An Phu district (D10) and As concentration at D11 (An Hoa hamlet, Khanh An commune), D33 & D36 (Hoa Ha hamlet, Kien An commune, Cho Moi district) and D38 (Phu Thuong 2 hamlet, Kien Thanh commune, Cho Moi district) exceeded the allowable limits. The CA results revealed that soil quality at 112 study sites was classified into 12 soil quality groups, possibly reducing the soil monitoring cost by 72.32%. As is the most significant contributor to potential ecological risks in soils, although RI values still showed that heavy metals pose a low risk in rice cultivation areas. However, heavy metals in soils could degrade soil quality, accumulate in agricultural commodities, and eventually humans through the food chain. Therefore, the frequency of the monitoring can be considered to increase to two or three times per year to evaluate the seasonal variation of the heavy metals.**

Index Terms—**An Giang, rice farming, heavy metals, potential ecological risk.**

I. Introduction

Heavy metal pollution frequently occurs in environmental media, especially in soil and water [1]. It was found that heavy metals can migrate in the soil environment to other components of the ecosystem, such as groundwater or plants, and can affect humans [2]. Some heavy metals in the soil are sources of micronutrients within appropriate concentrations. However, other heavy metals such as Pb, Cd, Hg and As have no beneficial effects on plants and animals and are considered toxic [3], [4]. In addition, many previous studies have demonstrated that agricultural cultivation is considered a significant source of additional heavy metal content in soil [5]-[8]. The presence of heavy metals in agricultural soil was mainly attributed to mining activities, waste disposal, application of organic manure, inorganic fertilizers, herbicides and pesticides [4], [9]. This suggests that heavy metal accumulation in plants may increase by plant root respiration in soils containing harmful heavy metals [3], [10]. As opposed to most organic contaminants, heavy metals are less susceptible to environmental degradation; therefore, the toxicity, non-biodegradability and durability of heavy metals in soil pose a potential danger to food security [6]. The hazard and risk assessment of soil samples are usually conducted by analyzing various physicochemical parameters. However, the individual evaluation of the parameters does not represent the total ecological risk level because the interactions between pollutants and soil substrates are not considered. To solve this problem, many studies have used the evaluation index based on the background values of the soil, namely, contamination factor (CF) and the ecological potential risk index (RI) [11]-[14].

In Vietnam, rice cultivation is considered the primary agricultural production activity, with about 7.3 million hectares of land used for agriculture, of which 4.3 million hectares are grown for rice, 1.3 million ha for perennial crops, and 0.3 million ha for grasslands. In rice cultivation in Mekong Delta, the use of pesticides in this area is higher than in other regions (the average number of pesticide sprays in this area (5.3 times/crop) is higher than in the Red River Delta (1.0 times/crop) [15]. This increases the risk of heavy metal accumulation in the soil. Typically, An Giang is one of the provinces in the Mekong Delta with the second-largest rice production compared to the whole country. However, the information on soil pollution and ecological risks in rice cultivation soil in An Giang province is very limited. Therefore, this study evaluated heavy metal concentrations and estimated ecological risk for rice-growing areas in An Giang province, Vietnam.

II. Materials and Methods

A. Description of the Study Area

An Giang is a border province in the Mekong Delta with a natural area of 353,668 ha, ranking fourth in the Mekong Delta (accounting for 8.73% of the entire area) and equaling 1.07% of the national area. The plains of the province account for about 87% of the natural area. The province has 11 administrative units equivalent to the district level, including An Phu, Chau Thanh, Chau Phu, Cho Moi, Phu Tan, Thoai Son, Tri Ton, Tinh Bien, Long Xuyen city, Chau Doc city, and town Tan Chau. An Giang has important waterways and land routes passing through. In addition, An Giang province has a watershed location, where waterways such as the Tien and Hau rivers connect other regions in the Mekong Delta with Laos, Cambodia, Thailand, and the East Sea. This is a favorable condition for the opening, integration, and development of the whole region with other countries. In terms of regional relations, An Giang is 200 km from Ho Chi Minh City, and 60 km from the center of Can Tho city.

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Therefore, it is one of the border provinces with an important strategic position in security, national defense, and economic development. It is the borderline adjacent to Cambodia about 90 km long, through 4 international border gates: Vinh Xuong, Xuan To, Long Binh and Vinh Hoi Dong.

In the province, the area of rice cultivation accounts for a large proportion and is effectively exploited and used. According to the Department of Agriculture and Rural Development of An Giang province, the rice area in 2019 accounted for about 625,400 ha (the Winter-Spring crop planted more than 235,000 ha; the Summer-Autumn crop about 230,000 ha and the Fall-Winter crop about 150,000 ha). The districts with the largest rice cultivation area are Tri Ton, Thoai Son, Chau Phu, Phu Tan, Cho Moi, An Phu and Tan Chau districts. The rice yield of the winter-spring crop is similar to the same period, so the average yield for the whole of 2018 in 2019 is 62.71 quintals/ha, equal to 99.5% (decreased by 0.31 quintals/ha) over the year. Total rice production for the whole year reached nearly 3.92 million tons. In the study area, large rice-farming areas comprise Khanh An commune (An Phu district), Kien An and Kien Thanh communes (Cho Moi district), Cho Vam town and Phu Thanh commune (Phu Tan district), Binh Duc ward (Long Xuyen city), and Luong An Tra commune (Tri Ton district).

B. *Soil Sampling and Analysis*

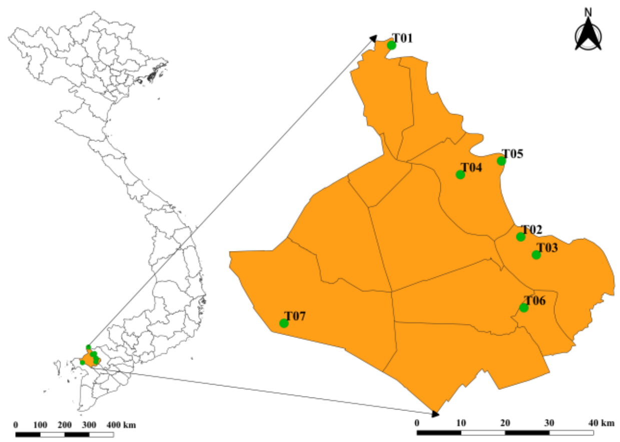


Fig. 1. Location of soil sampling sites in rice cultivation area at seven locations in An Giang province.

Soil quality data were collected from the Department of Natural Resources and Environment of An Giang province in 2020. Evaluation of heavy metal concentration in rice-growing soil in An Giang province was conducted in five districts, corresponding to five communes, one town and one ward with a relatively large cultivation area. Specifically, T01–Area for growing rice and crops in Khanh An commune (An Phu district), T02–Area for growing rice and crops in Kien An commune (Cho Moi district), T03–Area for growing rice and crops in Kien Thanh commune (Cho Moi district), T04–Rice growing area, Cho Vam town (Phu Tan district), T05–Rice growing area, Phu Thanh commune (Cho Moi district), T06–Rice growing area in Binh Duc ward (Cho Moi district) Long Xuyen City) and T07–Area for rice and crops in Luong An Tra commune (Tri Ton district) (Fig. 1). The study collected 112 samples in the study areas. Depending on the scale of farming in each area, the number of soil samples collected varied to ensure overall representativeness at each site. T01 with 24 samples of soil (D1–D24), including 14 locations on agricultural land (D1–D8; D18–D23) and 10 locations outside the cultivation area (D9–D17, D24); T02 with 12 soil samples (D25–D36) including 4 locations with dense farming patterns (D25–D28) and the remaining sites with relatively sparse farming patterns (D29–D36); T03 with 12 soil samples (D37–D48); T04 with 12 soil samples (D49–D60); T05 with 12 soil samples (D61–D72); T06 with16 soil samples (D73–D88) and T07 with 24 soil samples (D89–D112).

These soil samples were collected once time from 5-22 January 2020. At each sampling site, three soil samples were collected at the surface layer (0-30cm). After that, these samples were mixed and analyzed a pooled sample, which represented the site (about 1kg of the soil). This sample was collected according to TCVN 7538-2:2005 [16] and preserved according to TCVN 7538-6:2010 [17]. Before analysis, samples were air-dried at room temperature, removing impurities. Then, all soil samples were pulverized and sieved through a mesh with a pore size of 0.5 mm. The sampling methods of heavy metals are presented in Table I. While cadmium (Cd), lead (Pb), copper (Cu), zinc (Zn) were analyzed by flame and electrothermal atomic absorption spectrometric methods, arsenic (As) was analyzed by atomic absorption spectroscopy.

TABLE I. ANALYTICAL METHODS AND LIMIT VALUES OF HEAVY METALS

No.	Par. (mg/kg)	Analytical methods	LV[a]	WHO[b]	Thailand[c]
1	Cu	SMEWW3111B:2012	100	100	100
2	Zn	SMEWW3111B:2012	200	300	300
3	Pb	SMEWW3111B:2012	70	100	400
4	Cd	SMEWW3111B:2012	1.5	-	37
5	As	TCVN 6649:2000	15	20	3.9

[a] [18], [b][19], [c] [20]

C. *Data Analysis*

Concentrations of heavy metals at each location were compared with the national technical regulations on permissible limits of heavy metals in soil (QCVN 03-MT:2015/BTNMT) [18] (Table I). Boxplot was used to present the fluctuations of each heavy metal in each rice cultivation area. Cluster analysis (CA) was applied to identify the similarity of the survey sites based on the concentration of heavy metals [2]. In addition, the results of similarity grouping can reduce sampling locations to save survey costs in the future while still ensuring accuracy. In this study, the reduction of sites was based on two conditions of having the same cluster and the same study area. Cluster analysis was performed using Ward's method [21]. The CA results were presented by a dendrogram. CA analysis was performed using Primer 5.2 for Windows software (PRIMER-E Ltd, Plymouth, UK).

The ecological potential risk index (RI) method was used to assess the impact of heavy metal pollution in soil [22]. The RI can reflect the individual potential ecological risk of heavy metal as well as the overall risk level of an object [23], [24]. The ecological potential risk index method considers both the concentration of heavy metals in the environment and the toxicological response coefficient. The ecological potential risk index (RI) is determined according to the following formula [23]:

$$\mathbf{RI} = \sum_{p=1}^{n} \left(E_r^p \right) \qquad E_r^p = CF^p \times T_r^p$$

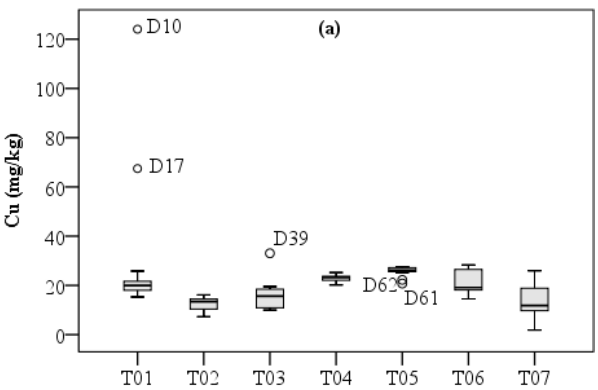
$$\mathbf{CF} = \frac{Cm}{Cb}$$

In which: E^p_r is the potential ecological risk coefficient of each metal; CF is the pollutant factor of each metal; T^p_r is the metal toxicity coefficient; Cm is the average concentration of metal observed; Cb is the corresponding background value of the metal; specifically, the background values of Cu, Zn, Pb and As suggested by Hien *et al.* (2019) [25] were 19.78, 47.16, 15 and 1.9, respectively. The level of Er is classified as follows: Er < 40, low risk; 40 ≤ Er < 80, moderate risk; 80 ≤ Er < 160, considerable risk; 160 ≤ Er < 320, high risk and Er ≥ 320, very high risk. T_r^p is the metal toxicity coefficient determined: Cu, 5; Zn, 1; Pb, 5; Cd, 30; As, 10. RI is an indicator of potential ecological risk, namely RI < 150, low risk; 150 ≤ RI < 300, moderate risk; 300 ≤ RI < 600, considerable risk and RI ≥ 600, high risk.

III. Results and Discussion

A. Heavy Metal Concentrations in Soil in Rice Cultivation Area

Heavy metals can be found in agricultural soils and crops of various origins, possibly of a natural source or a result of human activities. Heavy metals are still naturally available in the soil. The concentration of natural metals in the soil depends on the parent rock that forms the soil and is very variable. An Giang is a land formed relatively later than the rest of the area, mainly due to a marine transgression and regression, under the background of marine sediments, so the soil characteristics already exist a high concentration of certain metals. The analysis results show that the heavy metal concentration in the soil in the rice cultivation area of An Giang province is still within the allowable limit of QCVN 03-MT:2015/BTNMT [18]; however, As concentrations tended to exceed regulatory limits in soils in Thailand. In areas T01, T04 and T05, the concentration of heavy metals in the soil gradually decreased in the order of Zn > Cu > Pb > As. T02 has heavy metal concentrations in the soil decreasing progressively from Zn > Pb > As > Cu. Areas T03, T06 and T07 have heavy metal concentrations in the soil gradually decreasing from Zn > Pb > Cu > As. Particularly, Cd concentration was not detected in all soil samples. This is similar to previous studies in the region and other paddy fields in the world [8], [26].



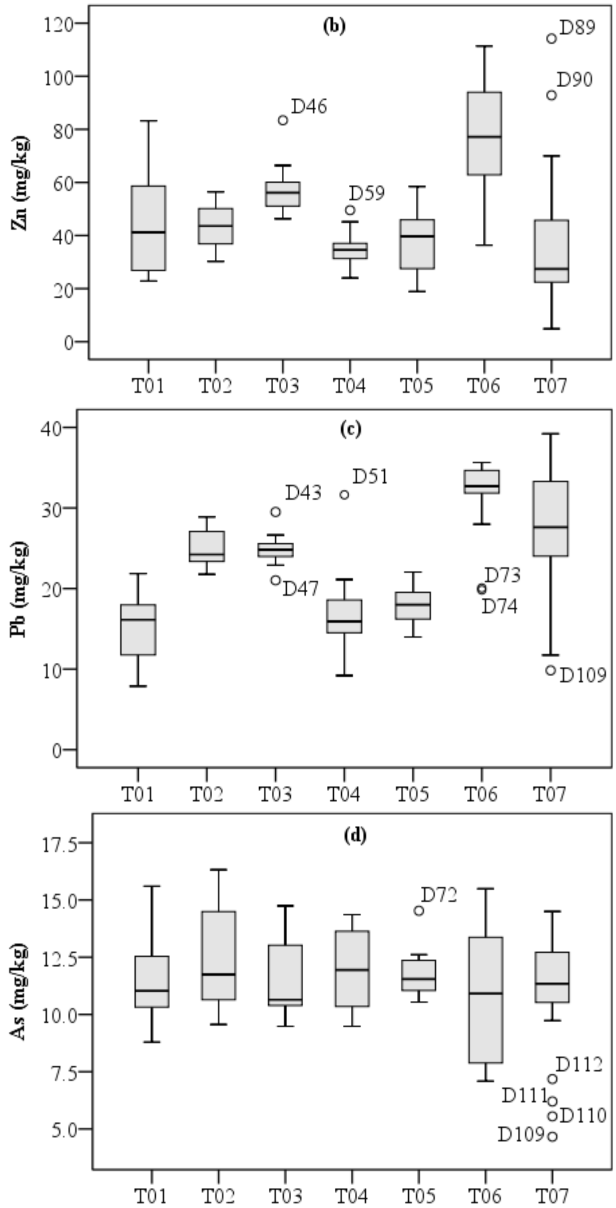


Fig. 2. Boxplot of the concentration of heavy metals in the soils under cultivation of rice Cu (a), Zn (b), Pb (c) and As (d).

The analysis results showed that Cu concentration in rice cultivation areas in An Giang province ranged from 1.83-124.04 mg/kg. Cu concentration in each area is shown in Fig. 2a. Cu concentration at T01 area ranges from 15.32-124.04 mg/kg with 2 positions D10 and D17 having relatively higher Cu concentration than the remaining sites. Especially at position D10, the Cu concentration exceeds the allowable limit of QCVN 03-MT:2015/BTNMT [18]. In this area, the average Cu concentration is the highest in 07 monitoring areas (Table II). Next is the T02 area, the Cu concentration fluctuates from 7.29-16.14 mg/kg. The Cu concentration in the T03 region varied in the range of 9.97-33.04 mg/kg and the D39 site had the highest Cu concentration, which was different from the rest of the sites in the same area. At T04 site, Cu concentration was relatively stable from 20.18-25.14 mg/kg. Areas T05 and T06 have Cu concentrations of 20.77-27.6 mg/kg and 14.55-28.31 mg/kg, respectively. Cu concentrations at two positions D61, D62 in the T05 areas were the lowest, relatively different from the remaining positions. In the T07 area, Cu concentration fluctuated relatively large from 1.83-25.92 mg/kg. The previous study in the paddy fields of the Nhue river basin showed that Cu concentration in soil samples was in the range of 27.61-55.28 mg/kg. This study reported that soil in Nhue River basin was influenced by polluted surface water [27]. Cu concentration in the Mekong Delta rice farm was 15 - 18 mg/kg [7], which was relatively lower than that in the present study. The difference could be because of the amount of fertilizer and pesticides used. Besides, fungicides are the main cause of Cu pollution in agricultural soils [28]. In general, Cu concentrations in most monitoring sites are within the allowable limit of QCVN 03-MT:2015/BTNMT [18], except the position D10, Cu exceeded the limit by 1.24 times.

As shown in Fig. 2b, Zn concentration in the T01 region fluctuated relatively large from 22.89-83.2 mg/kg. In the T02 area, Zn concentration fluctuated in the range of 30.24-56.42 mg/kg. In areas T03 and T04, Zn concentrations varied from 46.29-83.4 mg/kg, 24.02-49.55 mg/kg, respectively. Zn concentrations at D46 and D59 were higher than those in the locations in the same area. In the two areas T05 and T06, Zn concentrations fluctuated relatively large at 18.88-58.45 mg/kg and 36.38-111.35 mg/kg, respectively. In the T07 area, the Zn value also fluctuated relatively large from 4.87-114.18 mg/kg, especially the positions D89 and D90 had the highest Zn concentration. Through analysis, the paddy field in Binh Duc ward (Long Xuyen city) had the highest average Zn concentration (Table II). The results showed that Zn concentration in rice soil in An Giang province fluctuated in the range of 4.87-114.18 mg/kg. In some rice cultivation areas in Da Nang city, the Zn concentration is similar, ranging from 35.55-80.58 mg/kg, especially in the area near the industrial zone with higher Zn concentration than other areas [3]. Zn concentration in rice soil samples in Bac Lieu province ranged from 22.18 – 63.21 mg/kg [7], which is relatively lower than that in the present study area. Rice cultivation area along the Sinu River basin (Colombia) had an average Zn concentration of 955±455-1125±437 mg/kg due to the application of fertilizers, pesticides and fungicides [29]. In summary, Zn concentration at the monitoring sites is still within the allowable limit of QCVN 03-MT:2015/BTNMT [18].

TABLE II: MEAN VALUES OF HEAVY METALS (MG/KG) IN RICE CULTIVATION AREAS IN AN GIANG PROVINCE

Area	Cu	Zn	Pb	As
T01	26.17±23.14	44.06±18.76	15.20±3.88	11.36±1.66
T02	12.40±2.93	43.18±8.28	25.11±2.33	12.58±2.32
T03	16.19±6.31	57.56±9.92	24.85±2.05	11.61±1.76
T04	22.93±1.57	35.32±6.80	17.00±5.57	11.94±1.80
T05	25.68±2.12	37.74±11.70	17.82±2.39	11.83±1.1
T06	21.78±4.64	77.25±21.83	31.47±4.85	10.56±2.90
T07	13.01±6.70	37.63±25.91	27.22±7.63	10.94±2.65

As shown in Fig. 2c, Pb concentration in the T01 area varied from 7.87-21.85 mg/kg. Pb concentration in T02 area was in the range of 21.77-28.89 mg/kg. Pb concentration in the T03 region varied from 21.02 to 29.5 mg/kg in which Pb at D43 and D47 were relatively higher than other sampling locations in the same area. Area T04 with Pb concentration fluctuated relatively large from 9.2-31.63 mg/kg, especially the position D51 has the highest Pb concentration. The concentration of Pb in the T05 area ranged from 13.98 to 22.04 mg/kg. In T06 area, Pb value varied in the range of 19.81-35.65 mg/kg, in which the positions D73 and D74 had the lowest Pb concentration. Finally, Pb in the T07 area was from 9.84 to 39.22 mg/kg, and the lowest Pb concentration was found at D109. From Table II, Pb concentration was high in the paddy field of Binh Duc ward (T06). The results showed that Pb concentration in the entire rice-growing soil monitored in An Giang province varied between 7.87-39.22 mg/kg. This concentration tended to be higher in the soil in rice in Bac Lieu province (13.44-23.02 mg/kg) [7]. However, a previous study found that Pb concentration in the rice cultivation area was relatively low, in a range of 7.01-11.45 mg/kg [27]. This difference may be due to soil characteristics, which means that when the soil has a high organic matter content, the ability to accumulate Pb in the soil is high [7]. In general, the concentration of Pb at all monitoring sites was within the allowable limit of QCVN 03-MT:2015/BTNMT [18].

The findings revealed that the As concentration in the entire soil sample in the rice cultivation area in An Giang province ranged from 4.66 to 16.32 mg/kg. From Fig. 2d, the As concentration in the T01 area varied from 8.79 to 15.6 mg/kg, especially at the D11 site the As concentration exceeded the regulated limit by 1.04 times. T02 had As concentration ranging from 9.56 to 16.32 mg/kg with two locations (D33, D36) exceeded the allowable limit by 1.09 and 1.07 times, respectively. This is also the area with the highest As concentration (Table II). Areas T03 and T04 had As concentrations varying between 9.48-14.74 mg/kg and 9.48-14.36 mg/kg, respectively. As concentration in the T05 area ranged from 10.54 to 14.53 mg/kg, in which As at D72 was higher than other areas. T06 area had As concentration ranging from 7.09 to 15.49 mg/kg while As concentration at T07 was in the range of 4.66-14.5 mg/kg. A former study reported that As concentration in the rice farming system ranged from 2.2 to 6.8 mg/kg [30], which was lower than that in the present area. According to [7], the difference in As concentration can be attributed to the difference in different microbial and adsorption reactions controlled by chemical processes occurring in the soil. At the same time, the addition of chemical fertilizers, especially phosphate fertilizers, can also increase As concentration in the soil [30]. The analysis results show that the As concentration at the monitoring sites is mostly within the allowable limit of QCVN 03-MT:2015/BTNMT [18], except the locations D11, D33 and D36.

Cd concentration was found below the detection threshold in all observed soil samples. Soil may contain an average amount of Cd about 0.1 mg/kg [31] formed from weathering processes of minerals along major rivers in the Mekong Delta, especially in the area adjacent to the Cambodian border where the annual sedimentation is very high, can lead to a very high risk of Cd contamination. Among the heavy metals, Cd is not beneficial to humans and is potentially toxic [32]. Cd is a hazardous element even at low concentrations, and it will bioaccumulate in organisms and ecosystems [32]. All in all, it can be seen that the metal concentrations in the soil in the rice cultivation areas are within the allowable limits, except for a few locations where the Cu and As concentrations exceeded the limits specified by QCVN 03-MT :2015/BTNMT [18]. Although most of the heavy metal concentration is within the limit, heavy metals in the soil are extremely dangerous, potentially accumulating toxic substances in water.

B. Spatial Distribution of Heavy Metal Concentration

Heavy metal concentrations (Cu, Zn, Pb and As) in the soil of rice cultivation areas in An Giang province were used for the cluster analysis (CA). The CA results showed that 12 soil quality clusters were formed (symbols I - XII) from 112 monitoring locations (D_{link}/D_{max} < 60), and each cluster is a collection of the locations with similar soil quality based on overall heavy metal concentrations (Fig. 3). Sites that are in the same cluster and the same study area will be removed. Specifically, Cluster I was formed from three areas T01, T04 and T05. In which, T01 has included sites such as D1, D2, D4 – D7, D9, D13, D15, D16, D18 and D19; sites D53 – D56, D57 and D69 in the T04; D61, D62, D64 and D69 in the T05. Therefore, there were 19 sites that meet two conditions (same group and same research area) to reduce the number of sampling sites, which means only 3 sites are collected in the next studies. Similarly, sites D109, D110, D11 and D112 have been established as Cluster II; these locations are both located in the rice cultivation area T07. Thus, one of these two locations can be selected to monitor the heavy metal concentration in the soil. Cluster III included 13 sites, distributed in 4 study areas. Specifically, T02 - in Kien An commune (Cho Moi district) with three sites (D25, D28, D32, D34, D35); T03 –in Kien Thanh commune (Cho Moi district) with six sites (D38, D40 – D43, D47), T06 – in Binh Duc ward including one site (D85) and T07 – in Luong An Tra commune (Tri Ton district) with one site (D106). At the same time, Cluster VI, VII, and Cluster VIII were also formed from 10 sites (belonging to T01, T04, T05 and T07), 15 sites (belonging to T01, T03, T04 and T05), and 13 sites (belonging to T02, T03, and T07), respectively. Among the monitoring positions in Cluster VI, VII, VIII, one rice cultivation area in these clusters could select one site to collect soil samples. Similar soil properties were removed within a cluster similarly for clusters IX, X, XI, XII. Besides, Table III presents the average heavy metal content of the clusters. Notably, Cluster II had the lowest Cu and As concentrations, while Cluster IX and Cluster XII had the highest Cu and As concentrations, respectively.

After consideration, the number of monitoring locations could be significantly reduced. For example, rice cultivation areas at T01 and T07 have been reduced from 24 initial monitoring locations to 4 and 8, respectively. Cultivation areas at T02, T03, T04, T05 with 12 initial monitoring positions decreased to 3, 4, 4, and 3 sites, respectively. In the rice cultivation area at T06, there were 5 out of 16 sites that need to be monitored. Therefore, this reduction is likely to be lower the total costs of the soil monitoring program by 72.32%.

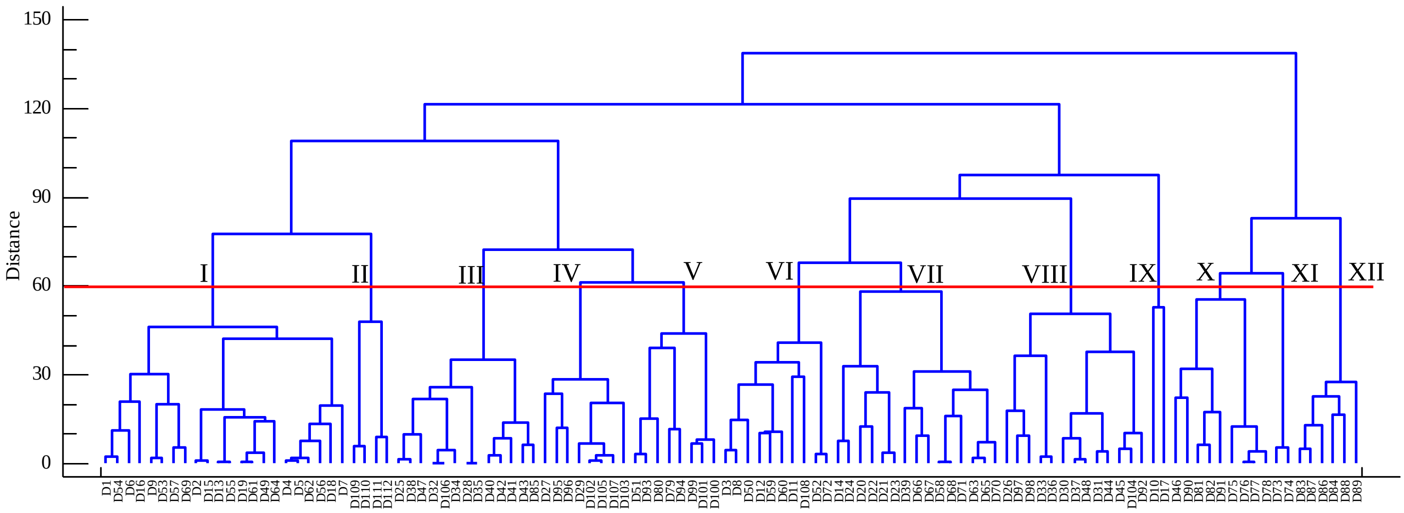


Fig. 3. Cluster analysis of heavy metals in soils in rice growing areas.

TABLE III: VALUES OF HEAVY METAL CONCENTRATION IN RICE CULTIVATION SOIL BY QUALITY GROUP

Metals	Clus.1	Clus. 2	Clus. 3	Clus.4	Clus. 5	Clus. 6	Clus. 7	Clus.8	Clus.9	Clus. 10	Clus. 11	Clus. 12
Cu	20.85	9.54	13.03	12.79	16.19	20.14	24.57	12.73	95.74	23.09	26.61	19.08
Zn	31.16	26.36	47.28	21.29	33.80	40.18	54.11	47.93	49.02	74.77	105.79	96.97
Pb	15.30	18.26	24.93	26.00	34.71	14.00	18.62	26.51	15.31	32.79	19.95	33.18
As	10.52	5.90	10.66	11.32	10.80	13.88	11.74	13.83	12.54	9.66	7.19	13.90

C. Potential Ecological Risk Level

The pollutant factor (CF) values showed high levels of contamination for As and moderate contamination for Pb according to the rating scale of Hakanson (1980) [23] in all study areas [Table IV]. Meanwhile, Zn and Cu indicate that the pollution level is at low – moderate level. The average pollution level of Zn was recorded in T03 and T06; T01, T04, T05 and T06 for Cu.

The RI method of soil heavy metal risk assessment has the potential to provide a quantitative value of the potential risk to ecosystems under the influence of pollutants [23]. Therefore, after determining the concentration and assessing the pollution level, RI was used to evaluate the ecological risk of Cu, Zn, Pb, Cd and As in rice cultivation soil. The ecological potential risk values were shown in Table V.

TABLE IV: THE LEVEL OF SOIL CONTAMINATION IN SITES WITH RICE CULTIVATION

CF	T01	T02	T03	T04	T05	T06	T07
Cu	1.32	0.63	0.82	1.16	1.30	1.10	0.66
Zn	0.93	0.92	1.22	0.75	0.80	1.64	0.80
Pb	1.01	1.67	1.66	1.13	1.19	2.10	1.81
As	5.98	6.62	6.11	6.28	6.23	5.56	5.76

TABLE V: ECOLOGICAL POTENTIAL RISK INDEX

Area	T01	T02	T03	T04	T05	T06	T07	Mean (Er)
Cu	6.62	3.13	4.09	5.80	6.49	5.51	3.29	4.99
Zn	0.93	0.92	1.22	0.75	0.80	1.64	0.80	1.01
Pb	5.07	8.37	8.28	5.67	5.94	10.49	9.07	7.56
Cd	0	0	0	0	0	0	0	0
As	59.79	66.21	61.11	62.84	62.26	55.58	57.58	60.77
RI	72.41	78.63	74.70	75.05	75.49	73.21	70.74	-

The potential ecological risk level (Er) showed that the ecological risk level for As is the highest, followed by Pb. Overall, the single risk exposure for metals is low. RI of Cu was 3.13-6.62 with an average of 4.99; Zn was 0.75-1.64 with an average of 1.01; Pb was 5.67-10.49, with an average of 7.56; As was 55.58-66.21 with an average of 60.77; Cd was 0. The single ecological potential risk factor for each heavy metal could be arranged in descending order as Er (As) > Er (Pb) > Er (Cu) > Er (Zn) > Er (Cd). These results indicate that serious accumulation of As has occurred in the study area. The composite ecological potential risk index (RI) presented a low level of potential ecological risk with the calculated values ranged from 70.74 to 78.63. The ecological risk of the study areas in increasing order was T07 < T01 < T06 < T03 < T04 < T05 < T02. As can be seen that the rice cultivation area in Kien An commune (T02) has the highest risk index, which has the relatively significant contribution of As. This can be explained by the impact of the unsanitary landfill located near paddy fields. Since heavy metals are highly persistent and accumulative, the occurrence of heavy metals in the long term could pose a potential risk to human health and the ecosystem through food webs. Monitoring heavy metals concentrations in the rice cultivation area is necessary for early warnings, which in turn minimizes human health and environmental risk.

IV. CONCLUSIONS

Heavy metals (Cu, Zn, Pb, As) were found in soil samples in the paddy fields of An Giang province. Most of the heavy metal concentrations were still within the allowable limits of QCVN 03-MT:2015/BTNMT. Nevertheless, at some locations, the concentration of Cu (D10) and As (D11, D33, D36, D86) exceeded the standards. Cd was found below the detection limit. Cluster analysis (CA) showed that the initial 112 sampling locations could be reduced to 31 sampling locations, which helps lower the monitoring costs by 72.32%. The ecological potential risk index showed overall ecological risk in the rice cultivation area is low. It is notable that As had the highest ecological risk between the analyzed heavy metals. Kien An commune had the highest risk compared to the other areas, which recommends converting cultivation and using rational fertilizers. The presence of heavy metals in soil in farming areas is a potential danger since heavy metals could bioaccumulate in agricultural products and ultimately affect human health through the food chain. The frequency of the monitoring can be considered to increase to two or three times per year to evaluate the seasonal variation of the heavy metals.

CONFLICT OF INTEREST

The author declares no conflict of interest.

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