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## EVALUATION OF THE ADSORPTION PROPERTIES OF TOPSOILS OF DONG NAI PROVINCE (VIETNAM)

## ОЦЕНКА АДСОРБЦИОННЫХ СВОЙСТВ ПОЧВ ПРОВИНЦИИ ДОНГ НАЙ (ВЬЕТНАМ)

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### Abstract

The features of the adsorption properties of various types of topsoils of the province of Dong Nai – Vietnam are presented. Three types of near-surface deposits are distinguished – Ferrasol, Luvisol and Acrisol, differing in their mechanical and chemical composition, pH value. Experiments were carried out to study the adsorption properties of these topsoils conditions of static sorption. The ICP-MS atomic adsorption spectroscopy method was used to determine the concentration of ions metal in solution after filtering. The results showed that the topsoils adsorbs arsenic and lead as much as possible. For certain types of topsoils, the features of adsorption ability were revealed, which is most manifested for the type of Luvisol, then Ferrasol and then Acrisol. The ability to adsorb heavy metals of Luvisols decreases in the following order: As > Pb > Cu > Cd > Zn. Ferrasols in the order of As > Pb > Zn > Cd > Cu. Acrisols in the order of Pb > As > Cu > Cd > Zn. Experimental results also revealed that, at high concentrations (100 mg/l to 1000 mg/l), Zn<sup>2+</sup>, Cu<sup>2+</sup> and Cd<sup>2+</sup> ions tend to move down to deeper soil layers.

### Аннотация

Экспериментальные исследования адсорбционных свойств различных типов почв центральной части Вьетнама были проведены в условиях динамической фильтрации растворов солей металлов (As, Cd, Pb, Zn, Cu) через образцы почв, помещенные в цилиндры высотой 25 см и радиусом 27 мм. Время фильтрации изменялось от 15 до 39 минут. Представлены особенности адсорбционных свойств различных типов верхних слоев почв провинции Донг Най (Вьетнам). Выделяются три типа почв: феррасоли, лувисоли и акрисоли, отличающиеся по своему механическому и химическому составу, pH. Были проведены эксперименты по изучению адсорбционных свойств этих почв в условиях статической сорбции. Метод атомной спектроскопии ICP-MS использовался для определения концентрации металла ионов в растворе после фильтрации. Результаты показали, что почвы адсорбируют мышьяк и свинец, максимально их поглощают. Для обозначенных типов почв особенности адсорбции отличаются, наиболее она проявляется для типа лувисолей, далее – феррасолей, а затем – акрисолей. Способность



адсорбировать тяжелые металлы лювисолой уменьшается в следующем порядке:  $As > Pb > Cu > Cd > Zn$ . Ferrasols по адсорбционным свойствам изменяется в ряду  $As > Pb > Zn > Cd > Cu$ . акрисоли адсорбируют в порядке  $Pb > As > Cu > Cd > Zn$ . Полученные результаты показывают, что при высоких концентрациях (100 mg/l to 1000 mg/l),  $Zn^{2+}$ ,  $Cu^{2+}$  и  $Cd^{2+}$  имеют тенденцию проникать в более глубокие горизонты.

**Keywords:** heavy metals, adsorption, luvisol, ferrasol, Acrisol, toxicity, Dong Nai, pollution.

**Ключевые слова:** тяжелые металлы, адсорбция, лювисоли, феррасоли, акрисоли, токсичность, провинция Донг Най, загрязнение.

## Introduction

Heavy metals penetrate agricultural land due to atmospheric deposition and the application of chemical fertilizers, animal manure, sludge and pesticides [Kosinova, Kustova, 2008; Ali et al., 2017]. An increase in heavy metal concentrations in the soil can cause serious problems for soil fertility, groundwater quality, and food chains [Mandzhieva et al., 2014]. The ability to penetrate substances through the soil environment has important effects on processes, such as groundwater and soil remediation, salt water intrusion, drinking water purification, and wastewater treatment [Pugliese et al., 2015]. It is also important for plant growth, chemical reactions (such as absorption, precipitation and redox) and to understand the environmental impact of landfills and surface-applied chemicals, such as pesticides and fertilizers [Breckle, 1991; Karup et al., 2016]. The main factors that govern the soil's absorption capacity are clay content, average particle diameter, pore distribution index, bulk density, organic carbon content and pH [Karup et al., 2016; Mojid et al., 2018]. According to some researchers, the level of heavy metal absorption in soils decreases in sequence: Clay > Fine dust > Medium dust [Baidina, 2001; Arthur et al., 2015]. The difference in the heavy metal absorption level of soils depends not only on the specific surface of the absorbent but also by their composition and properties [Mandzhieva et al., 2014]. According to authors like Breckle [1991], Gardea-Torresdey et al. [1996], Nies [1999], Meagher [2000], metals Arsenic, Lead, cadmium, copper, zinc and nickel, are the metals most commonly reported to have the highest impact on organisms.

Three types of soils are common in Dong Nai province: Ferrasols and Luvisols and Acrisols. Also in this province is the maximum number of industrial parks in Vietnam (33 large industrial parks, with lots of metallurgical, machine building, tanning, fertilizer, waste treatment plants ...). In this area, serious environmental pollution has also been recorded due to discharges from factories in 2011–2015. There have been reports of heavy metal contamination in surface water, such as Pb, Cd, and Zn exceeding the permissible level many times [Le, 2015]. This pollution moved to agricultural areas with irrigation system water. Farmers used contaminated river water to irrigate crops during the dry season (usually 3–4 times during the dry season from November to May). The simulation of the process by which soil absorbs metal ions when irrigated by contaminated water, will reveal the factors affecting the absorption process and the tendency to move metal ions in the soil.

## Materials and methods

**Materials:** We chose to use soluble salts of Zn, Cu, Pb, As, Cd at concentrations from 0.1 mg/l to 1000 mg/l. These metals were identified in the process of field research as the main polluting elements. Three types of soil include: Luvisols, Ferrasols developing on basalt and Acrisols developing on shale. The total area of these three types of soil accounts for 88 % of the total land area of Dong Nai province. The sampling depth is from 0–25cm (corresponding to the depth of topsoil). All samples were taken from agricultural land. Each type of soil was taken in three different places within agricultural areas (fig. 1). A 1 m<sup>2</sup> soil surface is cleaned of components such as roots, grass and other contaminants. Then, a pit is drilled with a shovel with a depth of 0.5 m, a width of 0.5 m and a length of 1 m. The ground surface has been leveled. Then

using a tape measure, mark the position of 25 cm from the ground to the bottom. Using a clean bag, place it under the trench, then use a plastic shovel, brush the soil vertically from the top of the soil surface to the marked location. The weight of each soil type were about 10 kg, then stopped. After collecting each type of soil, the impurities and roots were removed, then air-dried and sieved to particle size  $\leq 2$  mm. The pH of soil samples was measured using a Cyberscan digital pH meter. The total organic carbon (TOC) content in soil samples was measured by Walkley and Black's method [Allison, 1986]. The concentrations of metal ions in solution after filtering were measured with the help of an atomic absorption spectrophotometer ICP-MS. The analysis results of each soil sample were considered as the average value of each soil type.

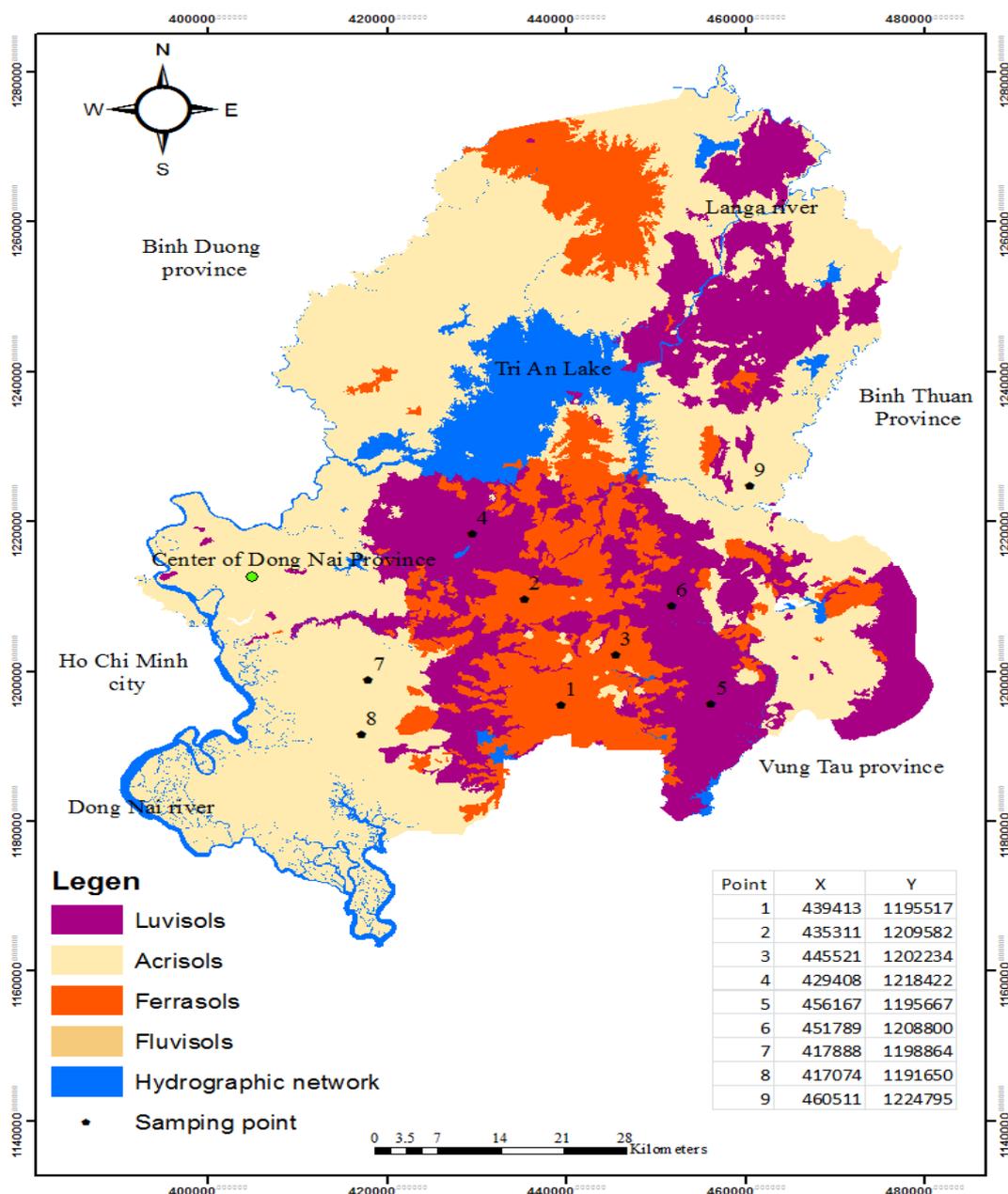


Fig. 1. Schematic of sampling points  
Рис. 1. Схема расположения точек опробования

Particle size composition, total organic carbon content and pH are considered to have a major influence on soil uptake. On the other hand, soil moisture and density are important in determining soil weight for experiments. Therefore, the above components and the concentrations of metals used in the experiment were analyzed in detail. Analytical results were given by table 1.

Table 1  
Таблица 1Results of soil sample analysis  
Результаты анализа проб почвы

| Parameter                    | Luvissols | Ferralsols | Acrisols |
|------------------------------|-----------|------------|----------|
| pH <sub>H2O</sub>            | 4.42      | 4.52       | 5.17     |
| Moisture, % (Dry Soil)       | 25.77     | 24.51      | 28.5     |
| Density (g/cm <sup>3</sup> ) | 1.34      | 1.19       | 1.30     |
| Porosity (%)                 | 60.06     | 55.19      | 53.54    |
| Total organic carbon (TOC %) | 1.46      | 1.43       | 0.98     |
| Sand (< 2 to 0.05 mm) %      | 16.6      | 20.2       | 61.1     |
| Silt (0.05 to 0.002 mm) %    | 37.2      | 17.6       | 17.4     |
| Clay (< 0.002 mm) %          | 46.2      | 62.2       | 21.5     |
| Total content As (mg/kg)     | 1.48      | 2.23       | 1.4      |
| Total content Pb (mg/kg)     | 6.8       | 4.61       | 4.22     |
| Total content Cd (mg/kg)     | < 0.017   | < 0.017    | < 0.017  |
| Total content Cu (mg/kg)     | 88.6      | 66.2       | 33.74    |
| Total content Zn (mg/kg)     | 116       | 127        | 56.18    |

Using a PVC pipe with a diameter of 27 mm and a height of 25 cm, drill directly into the ground at a depth of 25 cm from the soil surface at the sampling sites. In each location, one soil pipe was taken. The soil was obtained and dried at room temperature. The average weight of each soil type at the three sampling locations is the amount of soil used in the experiment pipe. The results: the amount of Luvisols soil to be filled into a test tube is 153.36 g, Ferrasols soil is 136.2 g, Acrisols soil is 148.7 g.

Conducting experiments: A 100ml Zn<sup>2+</sup> ion solution (Zinc nitrate hexahydrate) with a concentration of 0.1 mg/l was poured slowly into the plastic pipe containing Luvisols soil (plastic pipe with a diameter of 27 mm and a height of 25 cm, which was held on a stand vertically 90 degrees, The lower end of the pipe was covered with filter paper of ashless cellulose, with an average pore size of 8µm and a diameter of 150 mm), placed a graduated cylinder below the plastic tube containing soil to collect Zn<sup>2+</sup> ion solution after filtering through the soil.

The experiment was repeated 3 times. For 100 ml Zn<sup>2+</sup> ion solution with a concentrations of 1.0 mg/l, 10 mg/l, 50 mg/l, 100 mg/l and 1000 mg/l, the experiment was done in the same way. ICP-MS spectrophotometer was used to determine the concentration of metal ions in each solution obtained after filtering through the soil. The final result was the average value of the measurements, after eliminating the results with a large difference from the average value of 03 repetitions. The absorption capacity of the soil was the value of the initial metal ion concentration minus the concentration value of the solution after filtering through the soil. The salt copper chloride dihydrate, lead acetate trihydrate, sodium arsenite and cadmium sulfate octahydrate were similarly carried out. Excel 2007 software was used to determine the degree of correlation between soil absorption and metal ion concentration. Experiment on Ferrasol soil and Acrisol soil was carried out in a similar manner. The total number of samples tested was 90 samples for a soil type. The total of 3 types of soil is 270 samples.

## Results

The time for penetration of the saline solution through soil types is shown in table 2. According to table 2 these three soils have very different absorption time for the salt solution. Luvisols has the longest osmosis time, then Ferrasols and finally Acrisols. Metal ions also have different osmotic times. Can be classified into two groups, the groups of As and Cd have longer osmotic time than those of Pb, Cu and Zn. Arsenic has the longest osmotic time, possibly due to weak mobile As<sup>5+</sup> ions in acidic soils, which makes the solution penetrate the soil more slowly. This can be seen when the pH increases in the order of Luvisols – Ferrasols – Acrisols, the time

for absorbing arsenic salt solution decreases. The correlation between absorption time of metal salt solution and organic content in soil is very tight ( $r > 0.90$ ). As the organic carbon content increases, the penetration of the salt solution through the soil is hampered.

Table 2  
Таблица 2

Average osmotic time after filtration through soil  
Среднее осмотическое время после фильтрации через почву

| Soil type | Average absorption time (Minutes) |              |              |              |              |
|-----------|-----------------------------------|--------------|--------------|--------------|--------------|
|           | Cu                                | Zn           | As           | Cd           | Pb           |
| Luvisols  | 30.87 ± 2.32                      | 30.67 ± 3.02 | 38.76 ± 3.65 | 36.78 ± 2.86 | 32.87 ± 4.32 |
| Ferrasols | 25.32 ± 1.87                      | 27.43 ± 2.33 | 34.22 ± 2.54 | 32.29 ± 1.74 | 26.65 ± 3.23 |
| Acrisols  | 17.35 ± 2.04                      | 18.42 ± 1.45 | 24.37 ± 3.42 | 21.45 ± 1.47 | 15.24 ± 2.14 |

It can be seen that the differences in the time of penetration of metal salt solutions through the soil are strongly influenced by the size of the soil particles, the total organic carbon content and pH (table 3). While, the silt and clay particles are positively correlated ( $0.68 \leq r \leq 0.82$ ), the sand component has a strong inverse correlation with osmotic time ( $r > 0.94$ ). This proves that, when increasing the composition of small-sized soil particles, the solution osmosis time will increase and vice versa. This is the mechanism of absorption of soil solution, as the concentration of small-sized soil particles increases, corresponding to the increase in the surface area of soil colloidal particles, thereby increasing the ability to absorb ions.

Table 3  
Таблица 3

Correlation between absorption time and concentration of solution obtained with soil components  
Корреляция между временем поглощения и концентрацией раствора, полученного с почвенными компонентами

| Content         | Sand  | Silt  | Clay  | TOC   | pH <sub>H<sub>2</sub>O</sub> |
|-----------------|-------|-------|-------|-------|------------------------------|
| Cu osmosis time | -0.94 | 0.82  | 0.68  | 0.93  | -0.96                        |
| Zn osmosis time | -0.98 | 0.71  | 0.79  | 0.98  | -0.99                        |
| As osmosis time | -0.97 | 0.75  | 0.76  | 0.97  | -0.98                        |
| Cd osmosis time | -0.98 | 0.73  | 0.77  | 0.97  | -0.99                        |
| Pb osmosis time | -0.96 | 0.78  | 0.73  | 0.96  | -0.97                        |
| Zn 0.1 mg/l     | -0.43 | -0.49 | 0.80  | 0.45  | -0.39                        |
| Zn 1.0 mg/l     | -0.43 | -0.50 | 0.80  | 0.45  | -0.39                        |
| Zn 10 mg/l      | -0.45 | -0.48 | 0.81  | 0.47  | -0.41                        |
| Zn 50 mg/l      | -0.03 | -0.80 | 0.49  | 0.05  | 0.02                         |
| Zn 100 mg/l     | 0.69  | -0.99 | -0.28 | -0.68 | 0.73                         |
| Zn 1000 mg/l    | 0.89  | -0.88 | -0.58 | -0.88 | 0.91                         |
| Cu 0.1 mg/l     | -0.22 | -0.68 | 0.64  | 0.23  | -0.17                        |
| Cu 1.0 mg/l     | -0.25 | -0.65 | 0.67  | 0.27  | -0.20                        |
| Cu 10 mg/l      | -0.48 | -0.45 | 0.83  | 0.49  | -0.43                        |
| Cu 50 mg/l      | 0.75  | -0.97 | -0.37 | -0.74 | 0.78                         |
| Cu 100 mg/l     | 0.98  | -0.72 | -0.78 | -0.98 | 0.99                         |
| Cu 1000 mg/l    | 1.00  | -0.59 | -0.88 | -1.00 | 1.00                         |
| Pb 0.1 mg/l     | 0.74  | -0.97 | -0.35 | -0.73 | 0.77                         |
| Pb 1.0 mg/l     | 0.08  | -0.86 | 0.39  | -0.06 | 0.13                         |
| Pb 10 mg/l      | 0.87  | -0.90 | -0.55 | -0.86 | 0.90                         |
| Pb 50 mg/l      | -0.01 | -0.82 | 0.46  | 0.03  | 0.04                         |
| Pb 100 mg/l     | -0.36 | -0.56 | 0.75  | 0.38  | -0.32                        |
| Pb 1000 mg/l    | 0.85  | -0.92 | -0.51 | -0.84 | 0.87                         |
| As 0.1 mg/l     | -0.18 | -0.71 | 0.61  | 0.20  | -0.13                        |



Окончание табл. 3

|              |       |       |       |       |       |
|--------------|-------|-------|-------|-------|-------|
| As 1.0 mg/l  | -0.99 | 0.68  | 0.81  | 0.99  | -1.00 |
| As 10 mg/l   | -0.98 | 0.73  | 0.78  | 0.98  | -0.99 |
| As 50 mg/l   | -0.58 | 1.00  | 0.15  | 0.57  | -0.62 |
| As 100 mg/l  | 0.99  | -0.42 | -0.95 | -0.99 | 0.98  |
| As 1000 mg/l | 1.00  | -0.64 | -0.85 | -0.99 | 1.00  |
| Cd 0.1 mg/l  | -0.50 | -0.42 | 0.84  | 0.52  | -0.46 |
| Cd 1.0 mg/l  | -0.65 | -0.26 | 0.92  | 0.66  | -0.61 |
| Cd 10 mg/l   | -0.36 | -0.56 | 0.75  | 0.38  | -0.32 |
| Cd 50 mg/l   | -0.44 | -0.49 | 0.80  | 0.46  | -0.40 |
| Cd 100 mg/l  | 0.60  | -1.00 | -0.16 | -0.58 | 0.63  |
| Cd 1000 mg/l | 0.41  | -0.98 | 0.05  | -0.40 | 0.46  |

(Correlation coefficient was calculated based on the help of Excel 2007 software)

Soil pH is strongly inversely correlated with the time of salt solution osmosis ( $r = -0.96 - -0.99$ ). This is explained by the fact that when the pH is small, the charge on the colloidal-sized soil particles becomes more positive, leading to an increase in affinity for the anions of soluble salts, increasing the likelihood of colloidal-sized soil particles, increasing the absorption of soluble salts. In contrast, when the pH increases, it leads to the reversal of charges on the surface of the material, leading to repulsion of the anions, reducing the absorption of soluble salts, thereby faster permeation. This result is quite similar to that of Mojid et al. [2018], the velocity of metal ions was negatively correlated with the clay content in the soil ( $r = -0.99$ ), while pH had a positive effect on the velocity of metal ions moving in the soil ( $r = 0.76$ ).

According to table 3, when the metal ion concentration (Zn, Cu, As, Cd, Pb) is 50 mg/l or less, filtered through soil, forming an interesting rule. The soil's ability to absorb metals ion, at this concentration range, is directly proportional to larger particles (sand and silt) and inversely proportional to clay. This was shown by the negative correlation between the ratio of sand and silt particles to the concentration of the metal after filtration ( $r = -0.03$  to  $-0.8$ ) and positively correlated with clay particles ( $< 0.002$  mm). Although the smaller the soil particles, the affinity and surface area will be greater when absorbing metal ions: silt > physical clay > entire soil [Mandzhieva et al., 2014]. However, when the soil was dried and sieved to particle size  $< 2$  mm, the soil texture was broken. When the contaminant solution is poured into the test tube, fine particles will be swept down to the bottom of the tube, resulting in larger sized particles that will lie at the top. Metal ions move from top to bottom, so they will come in contact with the larger particles first. Due to the low ion concentration, it can be retained on the surface of these particles. As a result, when the concentration of infection is low, the absorption mainly takes place on the surface of silt and sand particles. At high concentrations (from 100 mg/l to 1000 mg/l) the uptake of metal ions into the soil particles of the soil varies. Most metal ions will be absorbed by silt and clay particles, as the composition of these particles increases, increasing the ability to absorb metal ions ( $r = -0.58$  to  $-0.99$ ). Conversely, when the content of sand grains increases, it reduces the absorption ( $r = 0.41$  to  $1.0$ ). This can be explained, when the metal ions at a high concentration, beyond the ability to absorb metal ions in the sand particles, the ions will be absorbed by the smaller particles when moving to the bottom pipe. In fact, when the soil is plowed, due to rain or watering, it is also clear that fine particles will tend to move downward, large particles will be on the top. From that, it can be seen that there are similarities in the metal ion absorption process of soil particles in the field and in the experimental model.

According to the fig. a–e, it can be seen that when the concentration of metal ions  $\leq 50$  mg/l, all metal ions are absorbed by the soil. From concentrations of 100 mg/l or more, the uptake of metal ions of the three soil types is different. Metal ion absorption properties of soils were also detected. The ability to absorb heavy metals decreases in order: Luvisols > Ferrasols > Acrisols. Absorption of metal ions decreases in the order of As > Pb > Cd > Cu > Zn.

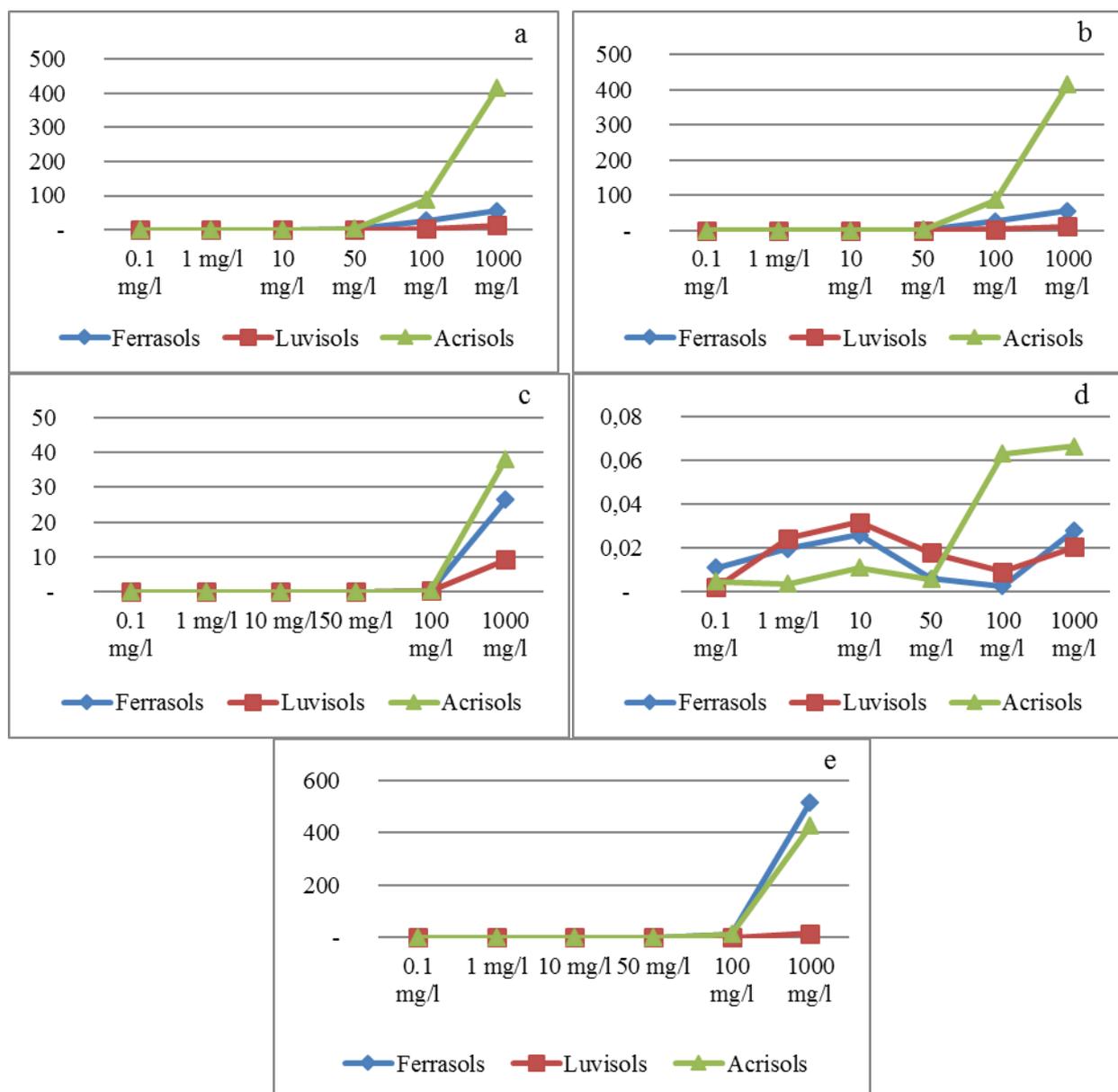


Fig. 2. The concentrations of ions were obtained after filtering through the soil:

a – Zn<sup>2+</sup>, b – Cu<sup>2+</sup>, c – Pb<sup>2+</sup>, d – As<sup>5+</sup>, e – Cd<sup>2+</sup>

Рис. 2. Концентрации ионов полученные после фильтрации через почву:

a – Zn<sup>2+</sup>, b – Cu<sup>2+</sup>, c – Pb<sup>2+</sup>, d – As<sup>5+</sup>, e – Cd<sup>2+</sup>

Soil pH value also affects the adsorption capacity of the soil. The tendency of anions or cations to adsorb depends on the pH. According to table 3, it can be seen that when the concentration is low (Cu<sup>2+</sup>, Zn<sup>2+</sup> ≤ 10mg/l; Cd<sup>2+</sup>, As<sup>5+</sup> ≤ 50mg/l) there is a weak positive correlation between the increase in absorbance and the pH. The metal ions concentration increases (from 50 mg/l to 1000 mg/l), it occurs in the opposite direction. Soil pH exhibits a very strong negative correlation with soil absorption. This may seem counterintuitive, however, as analyzed above, at low concentrations, ions are mostly absorbed by sand and silt particles. Meanwhile, soil pH is one of the most important parameters affecting the adsorption and ion exchange properties of clay minerals. It partly determines the degree of surface charge on colloidal soil particles [Mojid et al., 2018]. In other words, pH has a weaker effect on particles larger than clay. Therefore, at low concentrations, the effect of soil pH on absorption capacity is unclear, because the main component affecting soil absorption is the colloidal particle size. At high concentrations (from 50 mg/l to 1000 mg/l), there is a negative correlation between absorption and soil pH values



(very close correlation between pH and metal ion concentration after filtration  $r_{Cu} = 0.78$  to  $1.0$ ;  $r_{Zn} = 0.73-0.91$ ;  $r_{As} = 0.98-1.0$ ;  $r_{Cd} = 0.46-0.63$ ).

According to the results of table 3, at concentrations from 50 mg/l to 1000 mg/l, organic carbon is quite closely correlated with Cu absorption ( $r = 0.74-1.0$ ); Zn ( $r = 0.68-0.88$ ); As ( $r = 0.99$ ). For Pb and Cd uptake capacity, the correlation is weaker. This result also shows a similarity with Plyaskina and Ladonin [2005], which shows that more than 50% of copper and zinc are bound to organic matter and the remainder is closely linked to the components mineral soil, including iron.

### Discussion

The method of soil pollution with metals, carried out in this study, describes the process of absorbing heavy metals in the soil, such as when soil is contaminated with heavy metals during watering during the dry season, in the area of study. Normally, farmers usually create tanks around the tree and then water them. The simulation of this process, in order to determine the metal's ability to absorb metals of the topsoil (depth 0–25cm) in practice. The difference in this absorption process from the method used by some other researchers is the difference in the osmotic time, and how metal ions move in the soil. According to the method of Mandzhieva et al. [2014], soil is contaminated with heavy metals by mixing soil ratio and contaminated solution 1:10; Shake the suspension for 1 h. Leave to settle for 24 hours before analyzing the level of heavy metal uptake by the soil. With this method it is possible to determine the maximum absorption level of heavy metal ions, due to the collision process and the longer contact time between metal ions and soil particles. Obviously, the applied method has a shorter contact time between metal ions and the soil particles. The direction of movement of the metal ions from top to bottom along the test tube will result in a difference in soil uptake. However, the results still have similarities with the law of soil absorption. Soil uptake is highly dependent on particle size composition, pH and organic carbon content. However, the topic also discovered a change in the way the influence of these factors on the absorption of the soil. At low concentrations ( $< 50$  mg/l), pH and organic carbon content negatively affect absorption, but at higher concentrations, the opposite is true. This stems from the cause, metal ions are absorbed into different particle composition during absorption.

In soils, when the proportion of small sized particles such as silt, clay increases, the soil will have high absorption capacity, and conversely, if the sand content increases, the absorption capacity decreases. This is also confirmed by the research results of the authors Mandzhieva et al. [2014] and Mojid et al. [2018]. pH and organic carbon content also greatly affect absorption. Organic carbon content enhances the absorption of metals, while pH reduces the absorption capacity of the soil as their content increases [Minkina et al., 2006]. These results also have similarities in the observations of some authors [Karpukhin, Sychev, 2005; Plyaskina, Ladonin, 2005]. From the above analysis helped to evaluate the absorption of three soil types in the study area. Luvisols soil with the main components of clay and very rich humus, low pH, has the highest level of absorption of metal ions. Acrisols soil, the main component is sand, poor humus, high pH, so the level of absorption is lowest.

The absorption of metal ions decreases in the order of  $As > Pb > Cd > Cu > Zn$  due to the absorption characteristics of different soil particles. According to research results of Titova et al. [1996], the level of heavy metal accumulation of dust and alluvial soils, accumulating 25–65 %  $Cu^{2+}$ , 35–95 %  $Pb^{2+}$  and 53–89 %  $Zn^{2+}$ . This proves that Pb uptake capacity is greater than that of Cu and Zn. Similar results, also given by Mandzhieva et al. [2014].

At high concentrations (1000 mg/l), the surface layer of Acrisols soil absorbs about 52 %  $Zn^{2+}$  ions, about 85 % Luvisols soil and about 68 % Ferrasols soil. For Cd, the Luvisols soil is 98.4 %  $Cd^{2+}$ ; Ferrasols soil 49.4 %  $Cd^{2+}$  and Acrisols soil is 57.5 %  $Cd^{2+}$ ; for Cu, Acrisols soil is 58.5 %  $Cu^{2+}$ , Ferrasols soil is 94.5 %  $Cu^{2+}$  and Luvisols soil is 98.8 %  $Cu^{2+}$  (table 4). According to the experiment, almost all Pb and As ions are absorbed by the soil, although at very high con-

centrations (1000 mg/l). From the above analysis, we can conclude that for areas with sources of metal ions with concentrations < 50 mg/l, most remain in the topsoil (0–25cm). When the concentration of waste sources is higher, there is a risk of Cd<sup>2+</sup>, Zn<sup>2+</sup>, Cu<sup>2+</sup> ions moving to deeper soil layers, especially for Acrisols soil. Therefore, with the depth of groundwater in the study area from 8–12m, the possibility of contamination of groundwater by metals such as Cd, Zn, Cu can also occur, especially in gray soil area, in rain season when the groundwater table rises.

Table 4  
Таблица 4

Average concentrations of metal ions obtained after filtration through soil  
Средние концентрации ионов металлов, полученных после фильтрации через почву

|          | Metall | Ferrasols | Luvisols  | Acrisols  |           | Metall | Ferrasols   | Luvisols    | Acrisols    |
|----------|--------|-----------|-----------|-----------|-----------|--------|-------------|-------------|-------------|
| 0.1 mg/l | Zn     | 0.02      | 0.00      | 0.00      | 50 mg/l   | Zn     | 0.43±0.02   | 0.00        | 0.18±0.01   |
|          | Cu     | 0.05      | 0.00      | 0.01      |           | Cu     | 1.79±0.08   | 0.02±0.02   | 2.38±0.11   |
|          | Pb     | 0.00      | 0.00      | 0.00      |           | Pb     | 0.06±0.02   | 0.02±0.01   | 0.03        |
|          | As     | 0.01      | 0.00      | 0.00      |           | As     | 0.01        | 0.02±0.01   | 0.01±       |
|          | Cd     | 0.02±0.01 | 0.00      | 0.00      |           | Cd     | 0.20±0.05   | 0.00        | 0.00        |
| 1 mg/l   | Zn     | 0.15±0.01 | 0.00      | 0.00      | 100 mg/l  | Zn     | 43.99±0.96  | 16.48±0.41  | 49.86±0.99  |
|          | Cu     | 0.05      | 0.01±0.01 | 0.02      |           | Cu     | 26.80±2.23  | 3.26±0.16   | 87.42±0.56  |
|          | Pb     | 0.01      | 0.00      | 0.01      |           | Pb     | 0.36±0.01   | 0.25±0.01   | 0.26±0.01   |
|          | As     | 0.02      | 0.02±0.01 | 0.00      |           | As     | 0.00        | 0.01        | 0.06±0.03   |
|          | Cd     | 0.02±0.01 | 0.01      | 0.00      |           | Cd     | 12.55±0.56  | 0.00        | 13.16±0.44  |
| 10 mg/l  | Zn     | 0.36±0.01 | 0.01      | 0.00      | 1000 mg/l | Zn     | 322.66±2.6  | 149.07±1.38 | 482.75±5.18 |
|          | Cu     | 0.30±0.02 | 0.04±0.00 | 0.02      |           | Cu     | 55.22±1.11  | 12.34±0.89  | 415.85±1.45 |
|          | Pb     | 0.02      | 0.00      | 0.03±0.01 |           | Pb     | 26.45±0.01  | 9.17±0.01   | 38.22±0.01  |
|          | As     | 0.03±0.01 | 0.03±0.01 | 0.01±0.01 |           | As     | 0.03±0.01   | 0.02±0.01   | 0.07±0.05   |
|          | Cd     | 0.05±0.01 | 0.00      | 0.01      |           | Cd     | 516.81±0.54 | 16.69±0.43  | 425.12±0.74 |

According to Kosinova and Nguyen [2019], limited concentrations of certain metals in the soil that influence rice growth include: Pb ≤ 10 mg/kg; Cd ≤ 0.1 mg/kg. According to some previous studies, the concentration of Cu ≥ 25 mg/kg; Pb ≥ 10 mg/kg; Zn ≥ 100 mg/kg is considered toxic to plants [Tyler, 1974; Kabata-Pendias, Henryk, 1985; Allen, 1989]. The study area is mainly used for agricultural production (70–75 %), in particular for rice cultivation. Rice has roots, which are mainly located in the upper soil layer, ranging from 0–25 cm. The topsoils adsorb most metal ions when their concentration is ≤ 50 mg/l (especially Pb and As). Thus, over time, the topsoil can adsorb heavy metals in excess of the permissible level, which leads to environmental instability, inhibits plant growth, reduces productivity and causes poisoning of plants.

### Conclusion

The degree of absorption of metal ions depends on soil composition, pH and organic carbon content. In which Luvisols has the highest absorption capacity (almost > 80 %), then Ferrasols and Acrisols. The absorption capacity of Luvisols for metal ions decreases in the order of As > Pb > Cu > Cd > Zn; Ferrasols: As > Pb > Zn > Cd > Cu; Acrisols: Pb > As > Cu > Cd > Zn. According to the above sequence, it is possible to see the highest absorption of toxic metals, especially arsenic and lead. This is a potential danger, when there are sources of emissions of these toxic substances into the soil environment, especially land used for agriculture.

At different metal ion concentrations, the degree of soil absorption is also different. At concentration levels – 50 mg/l, almost all ions of Cu<sup>2+</sup>, Pb<sup>2+</sup>, Zn<sup>2+</sup>, Cd<sup>2+</sup>, As<sup>5+</sup> are absorbed by the topsoil. Most of the irrigation water used in agriculture has heavy metal ion concentrations in



this range. When the concentration of the metal ions increases, the level of heavy metal absorption of the soil is very different, of which at the concentration of 1000 mg/l, the absorption capacity varies greatly. Acrisols soil only absorbs about 50–60 %; Ferrasols soil is 60–70 % and Luvisols soil is 80–99 % metal ions.

Total carbon content and soil pH value have a significant influence on the ability of the soil to absorb heavy metal ions. As the total carbon content increases, the ability of the soil to absorb heavy metals increases. Meanwhile, when the soil pH value increases, the ability of the soil to absorb metal ions decreases.

Topsoil (0–25 cm) is capable of storing metal ions, especially lead and arsenic. This layer provides nutrients for plants, especially for vegetables and crops. Therefore, there must be measures to detoxify the soil if detecting soil contaminated with toxic metals such as As, Cd, and Pb. Metals such as Zn, Cd and Cu tend to go deep into the soil as their concentration increases (> 50 mg/l), which will lead to the possibility of contaminating groundwater.

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