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EVALUATING ECOLOGICAL RISK FOR THE OCCURRENCE OF HEAVY METAL IN SOIL IN INDUSTRIAL AREAS IN AN GIANG PROVINCE, VIETNAM

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Abstract

The study aimed to evaluate the concentration of heavy metals in the soil of industrial zones in An Giang province. Soil samples were collected at Binh Hoa and Binh Long industrial parks with 20 monitoring positions in the topsoil. The heavy metals including Copper (Cu), Zinc (Zn), Lead (Pb), Cadmium (Cd) and Arsenic (As) were analyzed by atomic absorption spectroscopy. The research results were compared with Vietnamese techinical regulation on the allowable limits of heavy metals in the soils (QCVN 03-MT:2015/BTNMT). In addition, the ecological potential risk index (RI) was applied to determine the level of risk of these industrial parks to the ecosystem using the risk assessment method of Hakanson (1980). The results showed that four out of five heavy metals including Cu, Zn, Pb and As were detected in the soil in Binh Hoa and Binh Long industrial parks at the concentrations of 24.7, 6.51, 14.18, 13.45 mg/kg and 22.63, 34.62, 2.87, 3.94 mg/kg, respectively. Most heavy metals are within the allowable limits of QCVN 03-MT:2015/BTNMT. However, As concentration at D3 and D8 points in Binh Hoa industrial park exceeded the standard by 18.79 mg/kg and 17.56 mg/kg, respectively. The results of RI showed that all the heavy metals pose low ecological risk in the study area. However, in the long term, the presence of heavy metals in the soil can be accumulated and affect ecosystems, which in turn impact human health. Therefore, monitoring of the soil and water environment for the detection of heavy metals is needed.

Keywords: An Giang; Industrial park; Heavy metals; Soil pollution.

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1. Introduction

Due to rapid industrialization and urbanization, the soil quality has been deteriorated, significantly higher concentrations of heavy metals. Soil heavy metal contamination is associated with anthropogenic sources such as mining, fossil fuel combustion and municipal and industrial waste [1]. Because heavy metals are durable, non - biodegradable, they can disperse and accumulate in the environment [2]. Therefore, this contamination can threaten ecosystems, surface water, groundwater, food quality and human health [3]. It is true that industrial activities constitute one of the primary anthropogenic sources that release heavy

metals into soils. For example, heavy metals (i.e., Pb, Cr, Cd, Cu, Ni, Zn) has been found in the production of electrical wires, batteries and electrical devices [4, 5]. Tiexi industrial district comprises various sectors such as metallurgy, chemistry, textiles, building materials and machine manufacturing, which resulted in high concentrations of Cu, Zn, Pb and Cd in topsoil [6]. Heavy metal pollution (Cd, Cr, Cu, Hg, Mn, Ni, Pb, Zn) in soil was also reported due to the impacts of industrial zones in Shanghai, China [7]. Therefore, it is necessary to determine the concentration of heavy metal in the vicinity of industrial zones.

In Vietnam, heavy metal contamination in soil has also become a major environmental problem. According to Vinh et al., (2012), the soil was significantly contaminated by heavy metals (Cu, Zn, As, Cd and Pb) that came from wastewater of the industrial zones in Phu Tho, Vietnam including phosphate fertilizer and chemical companies [8]. Doan et al., (2015) also reported that Pb and As contents were found in soil due to the impacts of Hoa Khanh industrial zone in Da Nang [9]. The sources of As, Cr, Cd, Cu and Pb in the soil in Nam Dinh province were from both natural and anthropogenic processes, including wastewater from industrial parks, production of traditional villages, agricultural activities [10]. However, studies on monitoring and evaluating heavy metal concentrations in soil in large industrial zones are still insufficient to investigate the long - term effects of industrial activities on the environment and human health.

An Giang is one of the key economic centers in the Mekong delta, the Southern region of Vietnam. Despite the impact of the Covid-19 pandemic, gross regional domestic product (GRDP) estimated in the first 9 months of 2021 increased by 1.60 % over the same period last year, of which the industry and construction sector increased by 2.05 %. It has two industrial parks in operation (Binh Hoa and Binh Long industrial parks), one industrial park preparing compensation plan (Binh Hoa industrial park expansion) and three planned industrial parks calling for investment (Vam Cong industrial park, Hoi An industrial park, Binh Long industrial park expansion). To the best of our knowledge, there are not many studies on heavy metal concentration in soil in industrial parks. Therefore, this study is to assess the heavy metal concentration in the industrial zone of An Giang province and estimate the ecological risk caused by the occurrence of heavy metals. The results of the current study could help the local environmental managers devise a planning strategy and effectively handle the heavy metal soil pollution in the region.

2. Material and methods

2.1. Description of the study area

An Giang province has an area of about 3,536.7 km^2 and a total polulation of 2,164,200 (in 2019). It is the headwaters of two large rivers, the Tien and Hau Rivers, which are important surface water sources in the Mekong delta. Binh Hoa industrial park was established in 2012 and is located in Chau Thanh district. It has an area of 131.78 ha and is occupied by 100 %. There were various types of products in this park such as building materials, garments, leather shoes, clean water supply, steel rolling, hot asphalt concrete, glass centers, machine manufacturing, solar energy and pharmaceutical production. The production of garments, footwear, solar energy and

medicines only generates solid waste collected in the factory. Meanwhile, metal and building material production are the sources of wastewater, gas and dust, solid waste containing some minerals, excess oil and grease, dust residue, iron oxides and other heavy metals, which are agents of soil and water pollution.

Binh Long industrial park located in Chau Phu district with an area of 28.56 ha (excluding Binh Long port with an area of 2.01 ha), occupying for 90 %. This park was established in 2019 and comprises seafood processing, fruit and vegetable food processing, aquafeed, fishmeal and fish fat production and clean water supply. The primary waste of these processes is in the liquid form, which arises in the process of soaking fresh food and seafood or in the process of cleaning production equipment. This wastewater, in addition to organic waste derived from animals and plants, also has a residual amount of pesticides, pesticides and preservatives in the cultivation process. Moreover, wastewater is also contaminated with oil due to leaks and spills during maintenance of machinery and equipment, floor washing water.

2.2. Soil sampling and analysis

The study was carried out in two industrial zones in An Giang province. Soil data was collected from the Department of Natural Resources and Environment of An Giang province. Twenty soil samples were taken at a depth within 0 - 30 cm with a plastic spatula in two industrial parks Binh Hoa (D1 - D16) and Binh Long industrial park (D17 - D20). The diagram of sampling locations of two industrial zones is shown in Figure 1 and Figure 2. Soil samples were collected according to TCVN 7538-2:2005 and preserved according to TCVN 7538-6:2010. These samples were dried at room temperature until reaching the constant mass, then ground and sieved. Heavy metals including Cu, Zn, Pb and Cd were determined using an atomic absorption spectrometer (AAS, Agilent, AA240) according to TCVN 6496:2009. Measurement results of heavy metal concentration in soil were evaluated against the national technical regulation on permissible limits of some heavy metals in soil (QCVN 03-MT:2015/ BTNMT).

Figure 1: Map of sampling location in Binh Hoa industrial park

Figure 2: Map of sampling location in Binh Long industrial park

2.3. Data analysis

The heavy metals at each location were compared with the national technical regulation on the allowable limit of some heavy metals in the soil - QCVN 03-MT:2015/BTNMT [11]. The ecological potential Risk Index (RI) method was used to assess heavy metal pollution. RI can reflect the individual potential ecological risk level of heavy metal as well as the overall risk level [12]. The ecological potential risk index method is one of the methods that is considered on both factors that are the concentration of heavy metals in the environment and the toxicological response coefficient. According to Hakanson (1980), the toxicity coefficients of metals (Cu, Zn, Pb, Cd and As) were determined to be 5, 1, 5, 30 and 10, respectively. Ecological potential risk index (RI) was determined according to the following formula:

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

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

In which: E^p_r is the potential ecological risk index for 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.

Table 1. Assessment of potential ecological risk

Risk	Er	RI
Low	<40	RI < 150
Moderate	40 ≤ Er <80	150 ≤ RI <30
Worrisome	80 ≤ Er < 160	300 ≤ RI <600
High	160 ≤ Er < 320	-
Very high	≥ 320	RI ≥ 600

3. Result and discussion

3.1. Evolution of heavy metals in industrial zones

The results indicated that four out of five heavy metals were detected in soil samples at monitoring locations of industrial zones in An Giang province. Cd content was not found in soil samples collected at Binh Hoa and Binh Long industrial parks. The average heavy metal concentration in decreasing order of Zn>Cu>Pb>As. In general, the heavy metal concentration in most soil samples is within the allowable threshold of QCVN 03-MT:2015/BTNMT [4].

Figure 3: Cu in industrial zones

From Figure 3, Cu concentration in Binh Hoa industrial park has a relatively low value, ranging from 10.45 to 33.18 mg/kg. The lowest Cu value was found at D3 by 10.45 mg/kg and the highest value was 33.18 mg/kg at D1. In Binh Long industrial park, the average Cu concentration was 22.63 mg/kg ranging from 18.89 to 27.44 mg/kg. The highest and lowest concentrations were found at D18 and D27, respectively. According to the study of Hien and Nhat (2021), Pb concentration in the agricultural soil around the industrial park was in the range of 9.4 - 79.8 mg/kg in Nam Dinh province due to the effect of traditional production villages and industrial parks surrounding this area [10]. Background Cu concentration in the soil can be found in the range of from 2 - 50 mg/kg [13]. Cu concentrations in soil were varied from 58.71 - 527.93 mg/kg because of the impact of Tiexi industrial zone in China [6]. It can be deduced that anthropogenic activities have an insignificant contribution to the presence of Cu in the soil. In general, heavy metals in the sampling locations in the two industrial zones are within the allowable limits of the national regulation on the limit of some heavy metals in soil - QCVN 03-MT:2015/BTNMT [11].

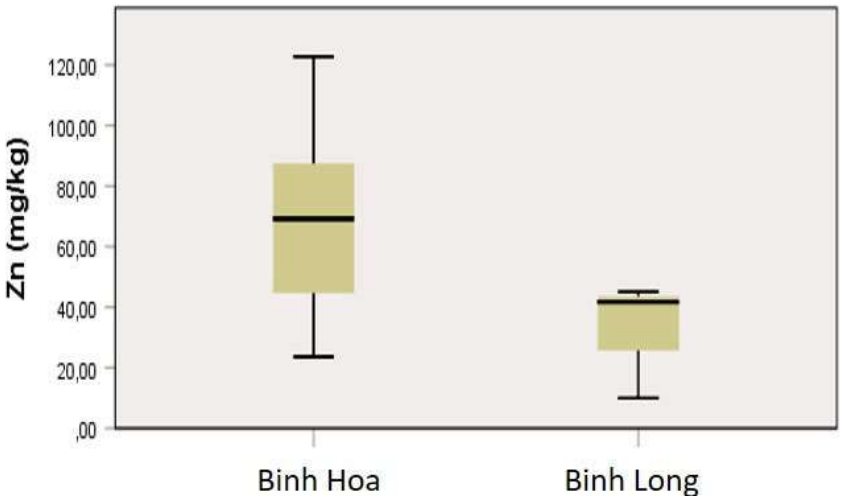

Figure 4: Zn in industrial zones

Zn concentration is higher than other metals detected in this study. The average Zn concentration in Binh Hoa industrial park was 68.52 mg/kg and fluctuated in the range of 23.59 - 122.74 mg/kg. Especially, the two points with very high Zn concentration were D2 (122.74 mg/kg) and D1 (110.14 mg/kg) located in the area adjacent to the Southwest of the industrial park. In Binh Long industrial park, Zn contents are lower than in Binh Hoa industrial park. Zn concentrations were ranged from 9.97 mg/kg (at D19) to 45.07 mg/kg (at D20), with an average of 34.62 mg/kg. This result is consistent with the previous study that the concentration of Zn present in the natural environment is about 17 - 150 mg/kg [14]. Wastewater from Cong River industrial park impacts the metal concentration of Zn in soil with values from 54.5 - 1432.5 mg/kg [15]. The average Zn concentration reached 178.6 ppb in the wastewater of factories and enterprises in Thuong Dinh industrial zone, which potentially causes heavy metal soil pollution [16]. The maximum Zn concentration in soils was 2495 mg/kg in the industrial sites of Albania [17]. In addition to the natural process, the impacts of Binh Hoa and Binh Long were slightly on the concentration of Zn in soil. The finding showed that Zn concentration in soil in the industrial zones is still within the allowable limit QCVN 03-MT:2015/BTNMT [11].

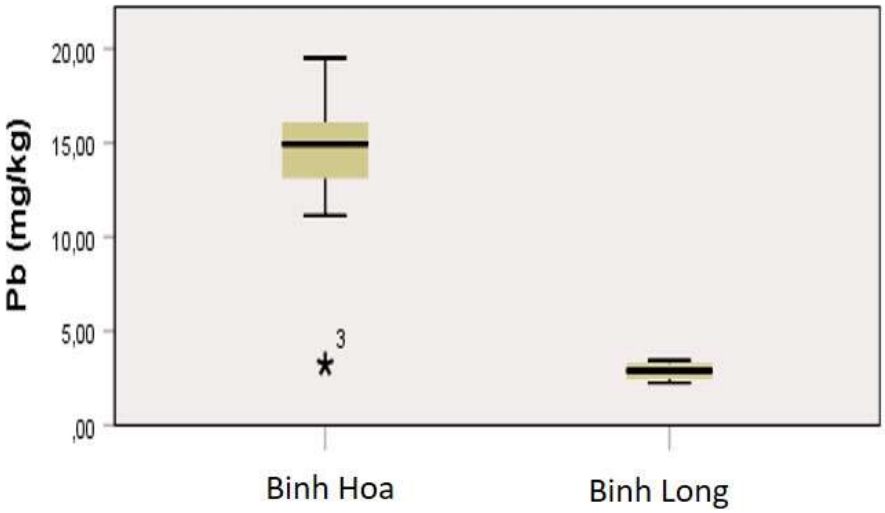

Figure 5: Pb in industrial zones

The results showed that Pb in Binh Hoa industrial zone was relatively low, with the average samples reached 14.19 mg/kg. There was a slight variation in the values between the samples ranging from 11.14 to 19.51 mg/kg. Only the Pb at the sampling point D3 reached a very low value (Pb = 3.23 mg/kg), while the highest value of Pb (19.51 mg/kg) was found at D1. In Binh Long industrial zone, the value of Pb metal is very low compared to the standard, with an average value of 2.87 mg/kg. The lowest value was found at D19 (2.24 mg/kg) and the highest was at D17 (3.45 mg/kg). The results revealed that the concentration of Pb at the sampling points are within the allowable limit of QCVN 03-MT:2015/BTNMT [11]. In nature, the concentration of Pb in the earth's crust is about 17 mg/kg [3]. According to Hai (2012), the Pb concentration in soil samples at the Van

Duong stream bank near the Cong River industrial park ranged from 0.45 to 140 0.0 mg/kg which is higher than that in the current study [15]. In addition to fossil fuel burning and mining, Pb is widely employed in the production of lead - acid batteries, ammunition, metal products [14]. Therefore, only factories related to the production of building materials, metal products in Binh Hoa industrial parks have potential to release Pb into the soil.

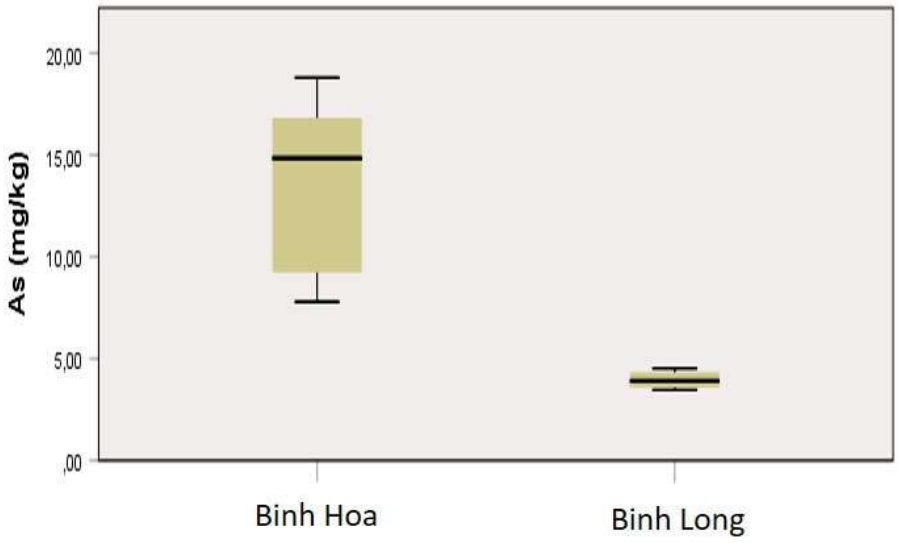

Figure 6: As in industrial zones

The findings showed that average As concentration in the soil in Binh Hoa industrial park was 13.45 mg/kg. The sample with the highest value was 18.79 mg/kg (D3) and the sample with the lowest value was 7.79 mg/kg (D16). In Binh Long industrial park, As concentration is relatively low compared to the standard, the average value of As in the samples was 3.95 mg/kg. As was the lowest at the position D19 (3.47 mg/kg) and the highest at position D17 (4.52 mg/kg). Compared with QCVN 03-MT:2015/BTNMT, As at the sampling locations was lower than that in the permitted threshold [11]. However, As concentration at the positions D3 (18.79 mg/kg) and D8 (17.56 mg/kg) in Binh Hoa industrial park exceeded the limit. As concentration in soil at the receiving point of wastewater of Cong river industrial zone reached values from 8.15 to 10.6 mg/kg [15]. According to Huang et al., (2016), total As concentration in soil in Dong Thap province was from 6 - 20 mg/kg [18]. The production of products related with agricultural applications such as herbicides, pesticides, wood preservative uses arsenic compounds [14]. Therefore, wastewater discharged from these industrial parks could be point sources of As pollution.

Among the heavy metals studied in the soil at the industrial parks, Cd is the metal that was not detected during the monitoring process and there was no sign appearing at the sampling locations in the industrial zones. Previous studies also reported that Cd was not detected or in insignificant concentration in all soil samples in the soil surrounding landfills [3, 19] . In natural soil, the average Cd concentration is about 0.1 mg/kg [15]. According to Tchounwou et al., (2012), Cd could be detected in wastes from manufactures of alloys, pigments and

batteries [14]. These products did not exist in Binh Hoa and Binh Long industrial parks.

It has been shown that the presence of heavy metals in the soil of the study area is due to the influence of activities in the industrial zones. Heavy metal parameters in Binh Hoa industrial park were higher than those in Binh Long industrial park because Binh Hoa has production activities of heavy industries such as metal and building materials production with emissions generated in the process. The production processes generate wastewater, gases and dusts, solid wastes containing pollutants and heavy metals causing environmental pollution.

3.2. Assessment of potential ecological risks

As can be seen in Table 2, the ecological risk factor (E_{pr}) of Cu was 1.23 and 1.13; Zn was 0.34 and 0.17; Pb was 1.01 and 0.21; As was 8.97 and 2.63 in Binh Hoa and Binh Long industrial park, respectively. The ecological risk factors of each metal in the soil in the industrial zone are arranged in the order of Cd< Zn< Pb< Cu< As. It is noticeable that As was the main ecological risk factor in the total five metals studied. Thus, according to ecological risk assessment method [12], Cu, Zn, Pb, Cd and As metals all had low ecological risks in this study. In Vietnam, there have not been many studies assessing the ecological risk of heavy metals in the soil in industrial zones. According to Li et al., (2020), the potential ecological risks of most heavy metals (As, Cr, Cu, Mn, Ni, Pb, Zn) except Cd and Hg were categorized as "low risk" (<40) [7]. Low ecological risks due to heavy metal contamination in the industrial area was reported in India [20]. Due to the different accumulation characteristics and waste sources, the level of accumulation and risk in different areas will be different.

Table 2. Potential ecological risk index for each heavy metal

Industrial park	E^p_r					RI
	Cu	Zn	Pb	Cd	As	
Binh Hoa	1.23	0.34	1.01	0	8.97	11.56
Binh Long	1.13	0.17	0.21	0	2.63	4.14

Heavy metals are usually low in concentration, but many elements can be toxic even at very low concentrations, elements such as As, Cd, Zn, Pb are highly toxic. According to US EPA (2011), the estimated maximum permissible on human through oral for As, Cd and Zn was 3×10^{-4} mg/kg-day, 5×10^{-4} mg/kg - day and 3×10^{-1} mg/kg - day, respectively [21]. Although heavy metals are naturally present in soils, metal pollution occurs mainly due to human activities. Metals at appropriate concentrations stimulate the respiration of microorganisms and increase the amount of CO_2 released. However, at high concentrations of Pb, Zn, Cu, Cd, the amount of CO_2 released decreases [22]. Many studies show a significant reduction in microbial biomass with increasing levels of toxic metals, some authors suggest that heavy metals have an effect on higher plants, such as causing leaf spot disease, reducing chlorophyll activity and reducing the products of photosynthesis [6 - 9]. Humans can be affected by contact with contaminated soil, or accumulated edible organisms. The threat becomes great when toxic substances through the soil seep into groundwater. Typical heavy metals that have an impact on human

health including Pb, As, Cu and Pb in which As and Pb are classified as human carcinogenic heavy metals [3]. Heavy metals could lead to adverse effects to human health [3 - 10].

4. Conclusion

It was found that four out of five heavy metals including Cu, Zn, Pb and As were detected in the soil in two industrial parks Binh Hoa and Binh Long. Most heavy metals are within the allowable limits of QCVN 03-MT:2015/BTNMT. As was found higher than the limit at the position D3 and B4 of Binh Hoa industrial park. Cd was not detected. All the heavy metals pose low ecological risk in the study area. The presence of heavy metals in the soil can be accumulated from wastewater of these two industrial parks and it could affect ecosystems as well as human health in the long run. Therefore, monitoring of the soil and water environment for the detection of heavy metals is needed.

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REFERENCES

[1]. Cenci, R. M. and Martin, J. M. (2004). *Concentration and fate of trace metals in Mekong river delta*. Science of the Total Environment 332, p.167 - 182.

[2]. Ministry of Natural Resources and Environment (2018). *State of the National Environment in 2018 - Water environment of river basins*.

[3]. Klinsawathom, T., Songsakunrungrueng, B., Pattanamahakul, P. (2017). *Heavy metal concentration and risk assessment of soil and rice in and around an open dumpsite in Thailand*. Environment Asia, 10(2), 53 - 64.

[4]. Adriano, D. C. (1986). *Trace elements in the terrestrial environment*. Springer, New York, 502 - 599.

[5]. Alloway, B. J., Ayres, D. C. (1997). *Chemical principles of environmental pollution*. 2nd ed. Blackie Academic and Professional, London

[6]. Li, F., Fan, Z., Xiao, P., Oh, K., Ma, X. and Hou, W. (2009). *Contamination, chemical speciation and vertical distribution of heavy metals in soils of an old and large industrial zone in Northeast China*. Environmental Geology, 57(8),1815 - 1823.

[7]. Li, Y., Yuan, Y., Sun, C., Sun, T., Liu, X., Li, J., Fang, L. and Fan, Z. (2020). *Heavy metals in soil of an urban industrial zone in a metropolis: Risk assessment and source apportionment*. Stochastic Environmental research and Risk assessment, 34(2), 435 - 446.

[8]. Vinh, N. C., Oborn I., Ha P. Q., Minh N. D., Hough R. L., Khai N. M., Thuy L. T. (2012). *Potential environment and public health risk due to contamination of heavy metals from industrial wastewater in Lam Thao, Phu Tho, Vietnam*. American Journal of Environmental Sciences; 8(1), 71 - 78.

[9]. Doan, C. C., Masaki, T., Vo, V. M. and Phan, N. T. (2015). *Heavy metals accumulation of food crops grown in agricultural areas affected by industrial wastewater, Da Nang, Vietnam*.

[10]. Hien, N. T. T. and Nhat, V. H. (2020). *Multivariate statistical assessment of heavy metals for agricultural soils in Nam Dinh province*. Institute of Geography, Vietnam Academy of Science and Technology.

[11]. Ministry of Natural Resources and Environment (2015). *QCVN 03-MT:2015/ BTNMT technical regulation on permissible limits of some heavy metals in soil*.

[12]. Hakanson, L. (1980). *An ecological risk index for aquatic pollution control - A sedimentological approach*. Water Research, 14(8), 975 - 1001.

[13]. Oorts, K. (2013). *Copper*. In: Alloway B. (eds) Heavy metals in Soils. Environmental Pollution, vol 22. Springer, Dordrecht.

[14]. Tchounwou, P. B., Yedjou, C. G., Patlolla, A. K., Sutton, D. J. (2012). *Heavy metals toxicity and the environment*. In: Molecular, clinical and environmental toxicology vol. 3: environmental toxicology (Ed: Luch A). Vol. 101 of the series Experientia supplementum. Springer Basel. 133-64.

[15]. Hai, T. T. M. (2012). *Research on the influence of wastewater from Cong River industrial park on the accumulation of heavy metals in sediments of Van Duong stream, Thai Nguyen province*. Master's Thesis in Environmental Science. University of Natural Sciences.

[16] Duc, N. V., Lan, T. N., Lan, P. T. (2001). *Contamination of heavy metals Fe, Mn, Cu, Pb, Zn, Cd, As and Hg in drinking water, industrial water and wastewater in industrial parks Thuong Dinh industry*. Ha Noi National University.

[17]. Shallari, S., Schwartz, C., Hasko, A., Morel, J. L. (1998). *Heavy metals in soils and plants of serpentine and industrial sites of Albania.* Sci Total Environ 209:133-142.

[18]. Huang, Y., Miyauchi, K., Endo, G. (2016). *Arsenic contamination of groundwater and agricultural soil irrigated with the groundwater in Mekong delta, Vietnam*. Environ Earth Sci 75, 757.

[19]. Giao, N. T. (2020). *Assessment of the environmental status before closing of the landfill in Dong Thang commune, Co Do district, Can Tho city*. Science and technology research at university level. Can Tho University. 71.

[20]. Bhutiani, R., Kulkarni, D. B., Khanna, D. R. and Gautam, A. (2017). *Geochemical distribution and environmental risk assessment of heavy metals in groundwater of an industrial area and its surroundings, Haridwar, India*. Energy, ecology and environment, 2(2),155-167.

[21]. USEPA (2011). *Risk assessment guidance for superfund*. Volume I Part A, Part E and Part F, pp. 540/1-89/002.

[22]. Chu, D. (2018). *Effects of heavy metals on soil microbial community*. In IOP Conference Series: Earth and environmental science (Vol. 113, no. 1, p. 012009). IOP Publishing.