

# EVALUATION OF THE SPATIAL DISTRIBUTION AND ACCUMULATION OF ARSENIC IN SOIL AT THE CORNER OF THE RUNWAY AT BIEN HOA AIRBASE, VIET NAM

Nguyen Thi Thanh Thao<sup>(1,4)</sup>, Dinh Van Huy<sup>(1)</sup>, Quach Duc Tin<sup>(1)</sup>,  
Phan Thi Loan<sup>(5)</sup>, Ngo Thi Thuy Huong<sup>(2,3)</sup>

<sup>(1)</sup>Viet Nam Institute of Geosciences and Mineral Resources

<sup>(2)</sup>Environmental Chemistry and Ecotoxicology LAB, Phenikaa University

<sup>(3)</sup>External Engagement Office, Phenikaa University

<sup>(4)</sup>Analytical, Environmental, and Geo-Chemistry, Vrije Universiteit Brussels, Belgium

<sup>(5)</sup>Port and waterway engineering consultant joint stock company

Received: 17/6/2024; Accepted: 16/7/2024

**Abstract:** The primary source of arsenic in soil is a combination of anthropogenic and natural weathering processes. The increased concentration of arsenic is a major issue due to its possible negative impacts on both ecosystems and human health. Considering these issues, this work conducts a rigorous and extensive investigation into the intricate dynamics of arsenic accumulation and contamination levels within soil matrices. The focus of this investigation is especially urgent, particularly in the context of the dioxin-contaminated environment. Specifically, the soil environment at Bien Hoa Airbase exhibits high levels of dioxin contamination.

A look at the values of the contamination factor, which ranges from 2.8 to 17.3, suggests indicators of a non-natural origin for the arsenic found in the soils. In addition, the arsenic quantities measured vary significantly, ranging from 9.9 mg/kg to 66.2 mg/kg, and the high accumulation distributed almost the Northeast of the study site. This observed range exceeds the World Health Organization's (WHO) and Viet Nam's regulatory guidelines. The contamination level is much higher than the background arsenic concentration. These results emphasize how critical it is to address and lessen the effects of anthropogenic arsenic pollution on the ecosystem and public health.

**Keywords:** Arsenic, concentration, ecological risk, contamination factor, Bien Hoa airbase.

## 1. Introduction

The source of Arsenic in the soil was weathering processes and industrial and resident activities [1], [2]. Exposure of humans to Arsenic through different sources, including contaminated groundwater and other human activities, has become a primary global concern [3]. Groundwater can become contaminated when arsenic minerals dissolve [4]. High amount of naturally occurring Arsenic in drinking water is a toxicological issue in several parts of the world [5], [6] and there was evidence linking exposure

to Arsenic to a higher risk of developing several malignancies [7], [8]. For many years, Arsenic has been used as a pesticide, fungicide, and herbicide [9]. A vast chemical agent as defoliants was used in the

War between Viet Nam and the US on Operation RANCH HAND in 1961-1971 [10]. Of these, a total of 72 million liters had been utilized by the three primary agents, Agent Orange (AO), Agent White (AW), and Agent Blue (AB) [(CH<sub>3</sub>)<sub>2</sub>AsOOH] [11-13]. In addition, one of the source of Arsenic contamination in Mekong delta was found from the War between 1961 and 1971, the United States frequently used Agent Blue to the rice paddies [12]. Agent Blue consists of an

Corresponding author: Ngo Thi Thuy Huong  
E-mail: huong.ngothithuy@phenikaa-uni.edu.vn

organic arsenic compound with a contamination level was found in the soil in Bien Hoa, Phu Cat, and Da Nang airbases [14]. The accumulation of arsenic in the soil at the Bien Hoa airbase was conducted from several samples, with the level of As content ranging from 25-30 mg.kg<sup>-1</sup> [15]. In another investigation, the spatial distribution of heavy metals and different pollution indicators were used to assess the environmental risk posed by heavy metals in the soil [16]. This study focuses on the spatial distribution and accumulation of As in the soil at the corner of the Bien Hoa Airbase runway and aims to: (1) Characterize the spatial distribution of As within the study area; (2) Quantify the level of As contamination in the soil; and (3) Evaluate the potential environmental and human health risks

associated with identified As levels.

## 2. Material and methods

### 2.1. Sampling collection

The study area encompassed a 600 m<sup>2</sup> section at the Southwest corner of the runway within the Pacer Ivy area of the Bien Hoa airbase. The specific location was defined by coordinates: latitude 10°58'41.94"N - 10°58'41.25"N and longitude 106°50'22.13"E - 106°50'21.66"E (Figure 1). A hand auger was used to collect the soil at a depth of 0-50 cm. Thirty soil samples were collected randomly throughout the 0-50 cm depth profile. An additional set of twelve samples was collected from four pre-selected sites within the study area. These twelve samples were further divided into three depth increments: 0-10 cm, 10-30 cm, and 30-50 cm.

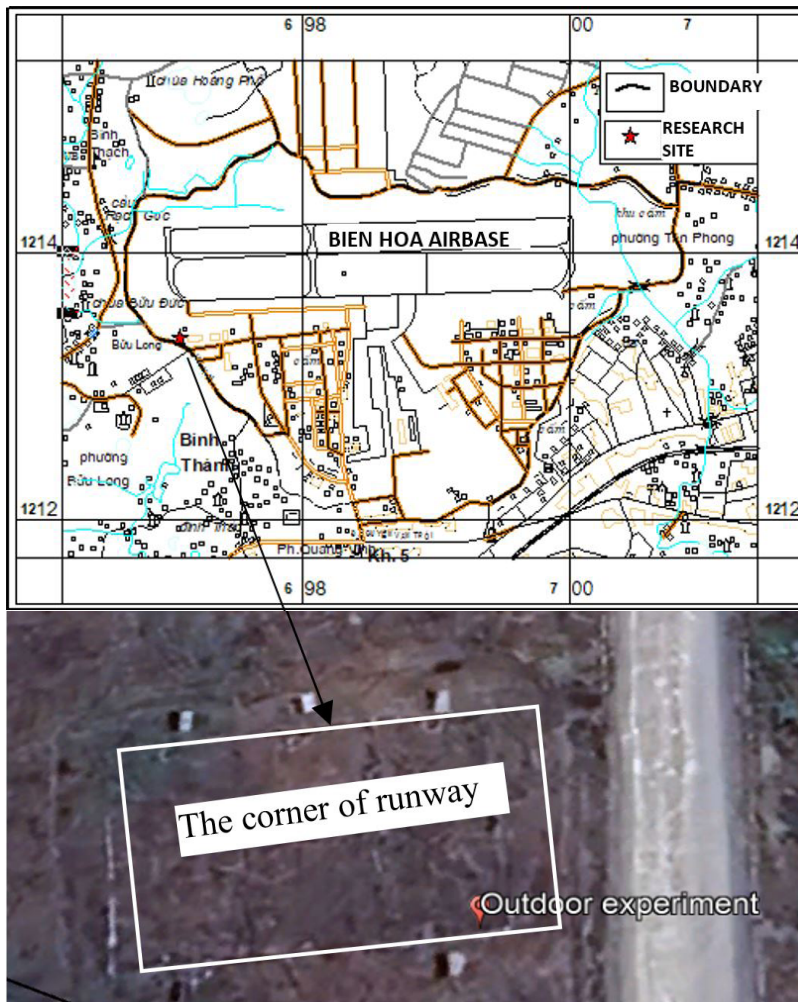


Figure 1. The study area (The Bien Hoa Airbase, Google Map 2023)

## 2.2. Analysis method

### 2.2.1. Analysis of total Arsenic

After being dried by the freeze-drying technique, soil samples were run through a 2 mm sieve. Approximately 0.1 g of dry soil was weighed and then digested in a Teflon vessel using an Anton Paar Muti-wave Go Plus microwave oven. The Teflon vessels were filled with 6 ml of concentrated acid nitric acid (67-69% Fisher, Trace Metal Grade), 2 ml hydrochloric acid (34-37% Fisher, Trace Metal Grade), and 4 ml hydrofluoric acid (40% Fisher, Trace Metal Grade). The Teflon vessels were heated using a temperature-controlled program in the microwave oven (hold at 180°C for 10 minutes after ramping up to 180°C). The samples were warmed in the microwave oven using the program ramp to 120°C during 10 minutes and hold at 120°C for 5 minutes after 30 milliliters of 4% boric acid was added after cooling. To ensure the accuracy and reliability of the analytical procedures, the certified reference material MESS 2 was processed and analyzed alongside the soil samples using the same protocol. After further diluting the digested samples, High Resolution Inductively Coupled Plasma Mass Spectrometry HR-ICP-MS (Thermo Scientific Element II) was used to examine them for trace elements (As). The analyses were conducted at the Analytical, Environmental, and Geo-Chemistry laboratory, Vrije Universiteit Brussels, Belgium.

### 2.2.2. Analysis of the physicochemical soil characterizations (OM, distribution of particle sizes)

The organic matter (OM) was determined by using the Walkley Black method [17]. Particle size distribution was performed by sieving [18] and the fractions sand (2000-50 µm), silt (50-5 µm) and clay (<5 µm) were determined.

## 2.3. Statistical Analysis and Data Processing

### 2.3.1. Contamination factor ( $C_f^i$ )

Pollution indices were calculated to evaluate the pollution status of the soils regarding trace metals. The contamination factor ( $C_f^i$ ) for each metal was calculated as the ratio of the mean

concentration of the metal to the background concentration of the metal ( $C_b^i$ ) (Equation 1). As a background concentration, the average concentration in Vietnamese soils was used [19].  $C_f^i$  values below 1 indicate low contamination,  $1 < C_f^i < 3$  moderate contamination,  $3 < C_f^i < 6$  considerable contamination and  $C_f^i > 6$  very high contamination [20].

$$C_f^i = \frac{C_s}{C_b} \quad (1)$$

### 2.3.2. Potential Ecological Risk index (Eri)

Heavy metals in soil or sediment are assessed from a sedimentological standpoint using the potential ecological hazard index Eri [20].

$$C_r^i = C/C_n^i \quad (2)$$

$$E_r^i = T_r^i \times C_r^i \quad (3)$$

Where:  $E_r^i$  is the potential ecological risk of metal;  $T_r^i$  is the toxic response factor (As = 10) [20].

$C_i$  is the measured concentration of metal n in marine sediments, and  $C_n^i$  is the standard value of metal n in the marine sediments. The conditions used to denote the risk factors and Ei according to are classified into nine categories of ecological risk as follows:  $E_r^i \leq 40$  = low;  $40 < E_r^i < 80$  = moderate,  $80 < E_r^i < 160$  = considerably,  $160 < E_r^i < 320$  = high,  $E_r^i > 320$  = very high [20].

### 2.3.3. Statistical analysis

Analysis of variance (one-way ANOVA) was used to assess the difference between sampling sites. The difference was considered significant at  $P < 0.01$ . Statistical analysis Multivariate statistical analysis method such as Pearson's correlation coefficient was used to determine the relationship between the properties of the soil and the concentration of arsenic. The IBM SPSS Statistics 29 was employed in this present study. The inverse distance weighted (IDW) approach using ArcGIS 10.2 software was employed for the analysis of the spatial distribution characteristics of Arsenic in the soil.

## 2.4. Quality control analysis

The accuracy of the analytical procedure

was tested through the analysis of certified reference material MESS 2 (sediment) for the acid digestion method. The recoveries of the total concentration of As in MESS 2 ranged from 103 to 118%. The blank samples and duplicate samples were also used in the analysis process.

### 3. Results and discussion

The initial characterization of the soil's physicochemical soil properties was performed through laboratory analyses. The organic matter (OM) content was determined to be  $1.61 \pm 1.10\%$  on average. The soil texture was analyzed using established laboratory methods. The results revealed a composition of  $65.11 \pm 4.26\%$  sandy particles,  $15.30 \pm 2.17\%$  silt particles, and  $19.59 \pm 5.28\%$  clay particles. This information provides valuable a baseline understanding of the soil's physical structure and potential influence on its chemical properties.

Table 1 presents the distribution of gravel, sand, silt, clay, and arsenic (As) concentrations across various soil depths at different sampling sites. Notably, a significant negative correlation was observed between sand content and depth. This suggests a decrease in sand fraction with increasing depth, which aligns with typical soil profiles where coarser particles like sand tend to be more abundant near the surface due to

sedimentation processes.

The observed decrease in arsenic (As) concentration with increasing depth suggests potential leaching or adsorption processes (Table 1). This trend aligns with the significant negative correlation ( $p < 0.05$ ) between sand content and depth, indicating a higher proportion of clay particles at lower depths (Table 2). Clays have a greater specific surface area and higher exchange capacity, promoting As adsorption and reducing its mobility [21]. Conversely, the higher sand content in surface layers likely contributes to the observed higher As concentration near the surface. This association suggests potential surface contamination and possible As mobility. The strong adsorption of As to larger particles, like sand coated with organic carbon and iron oxide ( $p < 0.05$ ) (Figure 5) (Table 2), can explain this phenomenon [22]. Additionally, previous research suggests that the leakage of chemical agents in the study area may have contributed to this surface enrichment [23].

These findings highlight the critical role of soil texture and depth variation in influencing As distribution and mobility within the soil profile. Considering these factors is crucial for accurate assessment of As contamination and development of effective remediation strategies.

Table 1. The distribution of particle size and the concentration of As in the soil

Sample	Depth (cm)	Gravel (%)	Sand (%)	Silt (%)	Clay (%)	As (mg.kg <sup>-1</sup> )
FC1(2/3)	0-10	2.20	70.82	11.92	15.06	23
FC1(2/3)	10-30	3.48	58.87	14.67	22.98	17
FC1(2/3)	30-50	4.90	58.27	12.57	24.26	19
FC3/3	0-10	7.23	68.08	11.32	13.37	39
FC3/3	10-30	8.46	56.69	13.63	21.22	21
FC3/3	30-50	2.86	57.86	14.08	25.20	14
FT1(2/3)	0-10	2.23	67.41	15.39	14.97	25
FT1(2/3)	10-30	17.14	57.81	11.27	13.78	25
FT1(2/3)	30-50	20.53	54.69	12.88	11.90	13
FT1(4/1)	0-10	13.31	70.36	10.40	5.93	18
FT1(4/1)	10-30	3.27	63.40	12.62	20.71	18
FT1(4/1)	30-50	8.39	65.68	11.52	14.41	16



Table 2. The correlation matrix between the distribution of particles and the concentration of arsenic

n = 12		Depth	Gravel	Sandy	Silt	Clay	As
Depth	Pearson Correlation	1	0.203	<b>-0.742**</b>	0.142	0.483	<b>-0.657*</b>
	Sig. (2-tailed)		0.526	0.006	0.659	0.111	0.020
Gravel	Pearson Correlation		1	-0.339	-0.472	<b>-0.596*</b>	-0.120
	Sig. (2-tailed)			0.281	0.122	0.041	0.711
Sandy	Pearson Correlation			1	-0.375	-0.536	0.438
	Sig. (2-tailed)				0.230	0.073	0.155
Silt	Pearson Correlation				1	<b>0.608*</b>	-0.233
	Sig. (2-tailed)					0.036	0.465
Clay	Pearson Correlation					1	-0.247
	Sig. (2-tailed)						0.440
As	Pearson Correlation						1
	Sig. (2-tailed)						

\*\* . Correlation is significant at the 0.01 level (2-tailed).

\* . Correlation is significant at the 0.05 level (2-tailed).

The study area is situated within the Bien Hoa Airbase, currently operational in the Northwest quadrant of Bien Hoa City (Figure 1). The airbase primarily functions as an active military facility, with a portion of the land designated for the cultivation of industrial plants. Analysis of soil samples revealed significant variation in arsenic (As) concentrations, ranging from 9.9 mg.kg<sup>-1</sup> to 61.66 mg.kg<sup>-1</sup> with an average value of 20.43 mg.kg<sup>-1</sup>. While this average concentration falls below the Vietnamese national standard limit for agricultural and residual soil (25 mg.kg<sup>-1</sup>) [24], it is considerably higher than the reported background concentration of 5.53 mg.kg<sup>-1</sup> [25].

By regulations established by the European Community (EC), the upper permissible threshold for arsenic content in agricultural soils is set at 20 mg.kg<sup>-1</sup> [26]. The study area exhibits a notable distribution of arsenic content, ranging from 20 mg.kg<sup>-1</sup> to 30 mg.kg<sup>-1</sup>, with a pronounced prevalence, particularly in the Southeastern region higher than this standard (Figure 2). Besides, in a small part of Northeastern, the high concentration of As with a range of 30-60 mg.kg<sup>-1</sup> is also higher than this one. Meanwhile, the accumulation of arsenic (As) concentrations ranging from 10 to 20 mg.kg<sup>-1</sup> is prominent in the Southwestern and Northwestern sectors

of the study area smaller than this standard recommended by EC. The observed spatial variation in As concentration may be attributed, in part, to the topographical slope of the study area. The western region, including Pacer Ivy, is characterized by flat terrain with a gradual westward slope [27]. This slope likely influences As runoff patterns, contributing to the observed disparity in As concentration [28].

Contamination factor ( $C_f$ ) values were calculated based on the As concentrations in the soil samples collected across the study area (Figure 3). The  $C_f$  values indicate a significant degree of soil contamination throughout the study area, ranging from "considerable contamination" ( $3 < C_f < 6$ ) to "very high contamination" ( $6 < C_f$ ) (refer to [30] for  $C_f$  classification details). This widespread contamination suggests potential sources such as dissolving arsenic compounds from nearby contaminated lakes, rivers, or groundwater (many arsenic compounds are water - soluble). Consequently, groundwater arsenic contamination poses a significant global health risk [29]. These findings highlight the necessity for ongoing monitoring and potentially expanding remediation efforts beyond currently identified high - contamination zones, if proper

management is not implemented [12].

The spatial distribution of the Potential Ecological Risk Index ( $E_i$ ) for arsenic within the study area is presented in Figure 4. The majority of the area falls within the category of moderate ecological risk ( $E_i = 40 - 80$ ), indicated by the yellow shading on the map [30]. This suggests widespread As contamination at levels that could potentially exert adverse effects on the local ecosystem.

However, several scattered regions depicted in orange represent areas of considerable ecological risk ( $E_i = 80 - 160$ ). These zones are primarily concentrated around the high-risk area (red) identified in the north-central part of the map, with additional scattered occurrences towards the center. These highlighted areas signify zones where elevated As concentrations pose a significant ecological threat.

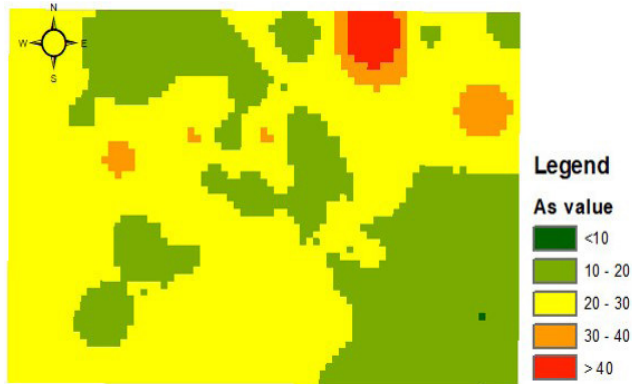


Figure 2. The spatial distribution of As in the soil in the study area

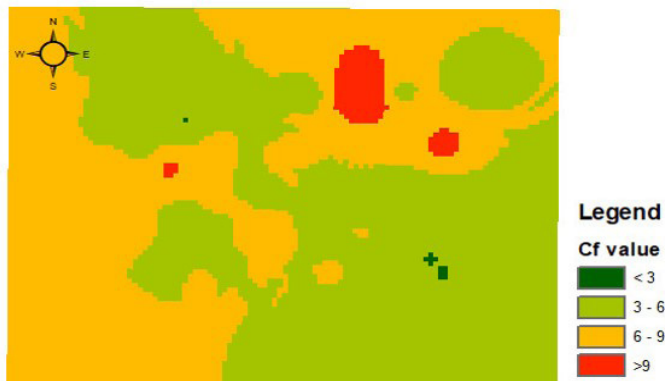


Figure 3. The contamination factor (Cf) of Arsenic in the study area

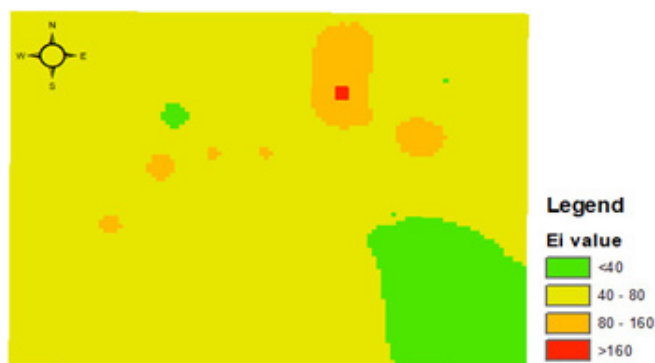


Figure 4. The potential ecological risk index (Ei) of Arsenic in the study area

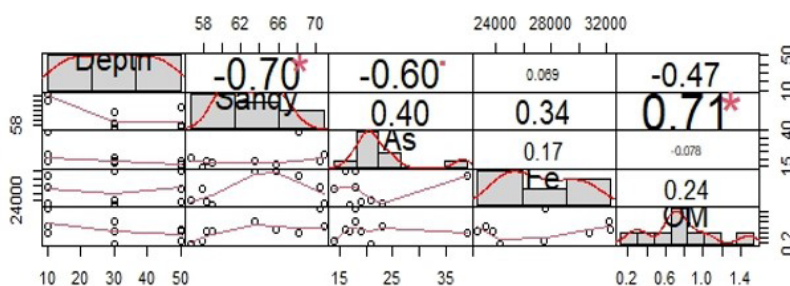


Figure 5. The correlation between sandy practices, Iron, Arsenic, and organic matter

#### 4. Conclusion

This study investigated the extent of arsenic (As) contamination in soil samples collected from the corner of the runway at Bien Hoa Airbase, Viet Nam. The primary objective was to assess the potential ecological risk posed by the contamination to the surrounding ecosystem and local population.

Analysis of the soil samples revealed significant As contamination, with concentrations ranging from levels indicative of "considerable contamination" to "very high contamination" based on established contamination factor ( $C_i$ )

classification.

The calculated  $E_i$  values indicated a substantial ecological concern across the study area. These findings highlight the urgent need for comprehensive environmental monitoring programs to track contaminant dynamics and assess potential ecological impacts.

The study underscores the critical importance of developing and implementing an effective remediation plan. Such a plan should aim to reduce As concentrations within the soil and mitigate potential adverse effects on the surrounding environment, safeguarding the health and well-being of local residents.

**CRedit authorship contribution statement:** All authors contribute in different ways and/or extend to this study. Nguyen Thi Thanh Thao: Investigation, Methodology, writing original draft, Review & Editing; Quach Duc Tin: Resource, Validation, Review & Editing; Dinh Van Huy: Field sampling, Investigation; Phan Thi Loan: Investigation, Methodology; Ngo Thi Thuy Huong: Conceptualization, Investigation, Methodology, Resource, Validation, Writing, Review & Editing, Supervision. All authors have read and agreed to the published version of the manuscript.

**Acknowledgements:** This research is a part of the project funded by USAID in the framework of PEER Cycle 6, grant number AID-OAA-A-11-00012. We are grateful to all the project members for their contributions and to the No. 935 Air Regiment for their great support during our experiments at Bien Hoa airbase. We thank the The Analytical, Environmental, and Geo- Chemistry lab, Vrije Universiteit Brussels, Belgium (VUB) for their assistance in sample analysis.

**Declaration of competing interest:** The authors assert the absence of any identifiable conflicting financial interests or personal relationships that might have been perceived as exerting influence on the findings presented in this paper.

#### Reference

1. Raju, N.J (2022), "Arsenic in the Geo-Environment: A Review of Sources, Geochemical Processes, Toxicity and Removal Technologies", *Environ Res*, 203, 111782, doi:10.1016/j.envres.2021.111782.
2. Patel, K.S. et al. (2023), "A Review on Arsenic in the Environment: Contamination, Mobility, Sources, and Exposure", *RSC Adv*, 13, 8803-8821, doi:10.1039/d3ra00789h.
3. Fatoki, J.O.; Badmus, J.A. (2022), "Arsenic as an Environmental and Human Health Antagonist: A Review of Its Toxicity and Disease Initiation", *J. Hazard Mater Adv*, 5, 100052, doi:10.1016/j.hazadv.2022.100052.

4. Chen, Q.Y.; Costa, M (2021), "Arsenic: A Global Environmental Challenge", *Annu Rev Pharmacol Toxicol*, 61, 47–63, doi:10.1146/annurev-pharmtox-030220-013418.
5. Hughes, M.F. et al. (2011), "Thomas, D.J. Arsenic Exposure and Toxicology: A Historical Perspective", *Toxicol. Sci*, 123, 305–332, doi:10.1093/toxsci/kfr184.
6. Muzaffar, S. et al. (2023), "Mechanistic Understanding of the Toxic Effects of Arsenic and Warfare Arsenicals on Human Health and Environment", *Cell Biol. Toxicol*, 39, 85-110, doi:10.1007/s10565-022-09710-8.
7. Nurchi, V.M. et al. (2020), "Arsenic Toxicity: Molecular Targets and Therapeutic Agents", *Biomolecules*, 10(2), doi:10.3390/biom10020235.
8. Kaur, R. et al. (2023), "Understanding Arsenic Toxicity: Implications for Environmental Exposure and Human Health", *J. Hazard. Mater. Lett*, 5, 100090, doi:10.1016/j.hazl.2023.100090.
9. Jiménez-Ballesta, R. et al. (2023), "On the Scarce Occurrence of Arsenic in Vineyard Soils of Castilla La Mancha: Between the Null Tolerance of Vine Plants and Clean Vineyards", *Pollutants*, 3, 351-359, doi:10.3390/pollutants3030024.
10. Young, A.L (2009), *The History, Use, Disposition and Environmental Fate of Agent Orange*, ISBN 9780387874852, 1-339, doi: 10.1007/978-0-387-87486-9.
11. Tuan Anh, M. et al. (2007), "Dioxin Contamination in Soils of Southern Viet Nam", *Chemosphere*, 67, 1802–1807, doi:10.1016/j.chemosphere.2006.05.086.
12. Olson, K.R. et al. (2020), "The Fate of Agent Blue, the Arsenic Based Herbicide, Used in South Viet Nam during the Viet Nam War", *Open J. Soil Sci*, 10, 518-577, doi:10.4236/ojss.2020.1011027.
13. Schechter, A. et al. (2022), "Recent Dioxin Contam Orange in Residents O", *Journal of Occupational and Environmental Medicine*, 43, 435-443.
14. Cox, T. et al. (2012), "Co-Contamination of Soil with Dioxin and Arsenic at Former Military Airbases in Viet Nam", *Conferece paper*, Vol. 74, 1365-1368.
15. Dinh, N.Q. et al. (2019), "Evaluating the Ability of Vetiver Grass to Reduce Dioxin and Arsenic Pollution in Soil at Bien Hoa Airbase", *Journal of Science: Earth and Environmental Sciences*, v. 34, n. 3, ISSN 2588-1094, doi:10.25073/2588-1094/vnuees.4262.
16. Santos-Francés, F. et al. (2017), "Spatial Distribution of Heavy Metals and the Environmental Quality of Soil in the Northern Plateau of Spain by Geostatistical Methods", *Int. J. Environ. Res. Public Health*, 14, 1-15, doi:10.3390/ijerph14060568.
17. Sahrawat, K.L (1982), "Simple Modification of the Walkley-Black Method for Simultaneous Determination of Organic Carbon and Potentially Mineralizable Nitrogen in Tropical Rice Soils", *J. Plant and Soil*, 77, 73-77.
18. Ministry of Agriculture and Rural Development (2011), *Soil quality - Determination of total organic carbon - Walkley Black method (TCVN 8941:2011)*, 1-8, (in Vietnamese).
19. Zarcinas, B.A. et al. (2005), "Heavy Metal Research in Vietnam: An Overview", *Int. Conf. Biogeochem. Trace Elem*, 94-95.
20. Hakanson, L. (1980), "An Ecological Risk Index for Aquatic Pollution Control. A Sedimentological Approach", *Water Res*, 14, 975-1001, doi:10.1016/0043-1354(80)90143-8.
21. Joardar, J.C.; Huq, S.M.I. (2005), "Adsorption of Arsenic (As) in Soils and in Their Clay Fraction", *J. Biol. Sci*, 14, 51–61.
22. Qi Zou et al. (2023), "Soil Particle Size Fractions Affect Arsenic (As) Release and Speciation: Insights into Dissolved Organic Matter and Functional Genes", *J. Hazard. Mater*, 443, Part B, 130100, doi:10.1016/j.jhazmat.2022.130100.
23. USAID (2016), *Report: Environmental assessment of dioxin contamination at Bien Hoa airbase*.
24. Ministry of Environment and Resources (2023), *Viet Nam National Technical Regulation on Soil Quality -QCVN 03:2023/BTNMT*, 10, (in Vietnamese)
25. Hung, N.T. et al. (2021), "Geo-Ecological Basis for the Prospect of Using Agricultural Territory of



*Dong Nai Province, Viet Nam* , *IOP Conf. Ser. Earth Environ. Sci*, 666, 052016, doi:10.1088/1755-1315/666/5/052016.

26. Rahman, M.S. et al. (2023), "Accumulation of Arsenic and Other Metals in Soil and Human Consumable Foods of Meherpur District, Southwestern Bangladesh, and Associated Health Risk Assessment", *Environ. Sci. Eur*, 35, 1-10, doi:10.1186/s12302-023-00751-2.
27. Thuong, Van, N. et al. (2014), "Transport and Bioaccumulation of Polychlorinated Dibenzo-p-Dioxins and Dibenzofurans at the Bien Hoa Agent Orange Hotspot in Viet Nam" , *Environ Sci Pollut Res*, 22(19):14431-14441, doi:10.1007/s11356-014-3946-9.
28. James, K.A. et al. (2016), "Arsenic", *Int. Encycl. Public Heal*, 1, 170-175, doi:10.1016/B978-0-12-803678-5.00025-4.
29. Argos, M. et al. (2010), "Arsenic Exposure from Drinking Water, and All-Cause and Chronic-Disease Mortalities in Bangladesh (HEALS): A Prospective Cohort Study", *Lancet*, 376, 252-258, doi:10.1016/S0140-6736(10)60481-3.
30. Kone, K.; Kouakou, A.R, "Assessment of Soil Contamination and Human Health Risk around an Industrial Gold Mine in Côte d'Ivoire: The Case of Arsenic", *Open J. Soil Sci*, 13, 329–339, doi:10.4236/ojss.2023.137014.