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THE HEAVY METAL CONSTITUENTS AND COMPOSITION OF THE SOIL AND MUSHROOMS COLLECTED FROM THE NONG-AUNG PUBLIC FOREST

PATARAPONG KROEKSAKUL*

Faculty of Environmental Culture and Ecotourism, Srinakharinwirot University, 10110 Bangkok, Thailand.

*Corresponding author: patarapong@g.swu.ac.th
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Abstract: This paper presents the findings of a study conducted to assess the conditions and heavy metal contents of the soil in areas of the Nong-Aung public forest. This study investigates the relationship between the heavy metal contents in soil and the accumulation of heavy metals in naturally occurring mushrooms within the public forest, comparing the components of a waste disposal zone and a general disposal zone. This study employs one-way analysis of variance to analyse variances between groups, with data differences compared using the least significant difference method. The research reveals significant differences ($p < 0.05$) in the heavy metal contaminants present in soil between the waste disposal zone and the general zone in the public forest. Human activities are found to influence soil properties and heavy metal content. However, it is important to note that the levels of heavy metals in the Nong-Aung public forest do not exceed Thailand's standards. The study also examines the heavy metal content in various mushroom species, including *Mycoamaranthus cambodgensis* (Pat.) Trap, *Ganoderma applanatum* (Pers.ex Wallr.) Patouillard, *Heimioporus japonicus* (Hongo) E. Horak, *Thaeogyroporus porentosus* (berk. ET. Broome) and total mushrooms suitable for consumption. The research reveals that the mushrooms have an average Cd content of 0.558 ± 0.908 mg/kg dry weight, with quantities of other elements as follows: Pb 1.740 ± 2.441 mg/kg dry weight, Mn 266 ± 128 mg/kg dry weight, Ni 4.44 ± 2.83 mg/kg dry weight, and As 0.014 ± 0.005 mg/kg dry weight. Importantly, the heavy metal content of mushrooms in the public forest does not exceed the established standards. However, the study highlights concerns regarding the quality of soil in the public forest and its potential impact on the environment and local biodiversity. The paper concludes by emphasising the need for local government and citizen advocacy to impose restrictions on the expansion of waste disposal areas in the public forest.

Keywords: Heavy metal, bioaccumulation, west dump, public forest, mushroom.

Introduction

Heavy metals found in the soil parent are also present as constituents of the soil in that specific area (Wuana & Okieimen, 2011; Zheng *et al*., 2012). Heavy metal contamination in the soil is influenced by the release of metals such as lead (Pb), copper (Cu), cadmium (Cd), zinc (Zn), nickel (Ni), and iron (Fe) through transportation activities (Kummer *et al*., 2009; Choi *et al*., 2020; Liu *et al*., 2022). Additionally, leaching processes can lead to soil contamination with metals like arsenic (As), chromium (Cr), manganese (Mn), selenium (Se), and Fe, especially in waste dump sites (Lekfeldt *et al*., 2017; Chu & Ko, 2018; Agbeshie *et al*., 2020; Akanchise *et al*., 2020; Essien *et al*., 2022). This leaching is partially due to the decomposition of waste materials containing these heavy metals (Zhang *et al*., 2017). These findings indicate that heavy metal pollution of the soil can result from both natural and human-induced processes, posing a potential risk to the food chain, including mushrooms.

In the northeast region of Thailand, natural mushrooms typically emerge during the early rainy season in May, primarily in mixed deciduous forests or public forests near communities. These forests are considered public resources and are used for natural foraging. The value of natural food sources in these forests, including mushrooms, is approximately 19,200 baht per year, providing significant economic support to villagers who gather mushrooms for household consumption and for sale. The natural food industry, including mushroom products, generates an annual income of about 30,000-60,000 baht, with mushrooms accounting for over 45% of this total value (Srichaiwong *et al.*, 2014). However, there have been reports of heavy metal contamination in natural mushrooms, including Pb, Zn, Fe, Cu, and Ni. This contamination is attributed to the deposition of these metals from the soil in the mushroom's area of origin (Campos *et al*., 2009; Kokkoris *et al*., 2019).

The Nong-Aung public forest shares similarities with the forests in northeastern Thailand, particularly being a mixed deciduous forest that serves as a source of mushrooms and other natural food for the local community. However, this forest area also receives organic and inorganic household waste. Villagers have noticed an increase in the occurrence of natural mushrooms in the waste dumping area within the public forest. This increase has prompted the research questions addressed in this study:

(1) Does the practice of villagers depositing waste in the public forest area lead to an accumulation of heavy metals in the soil?

(2) Do the natural foods in these areas exhibit high concentrations of heavy metals?

(3) Can the soil conditions in the area designated for waste disposal undergo changes?

These research questions guide the investigation into soil conditions and heavy metal content in public forest areas, specifically by examining the relationship between heavy metal levels in the soil and their accumulation in natural mushrooms within the public forest area in Nong-Aung Sub-district, Rasi Salai District, Si Sa Ket Province. This study aims to establish an environmental database in the community, facilitating the learning process and fostering a connection between the local community and environmental management. The heavy metals of interest in this research are Pb, As, Cd, Cu, Mn, and Ni, as these elements are commonly found in organic waste, which constitutes a significant portion of the garbage in this region.

Materials and Methods

Study Site and Sample Collection

The Nong-Aung public forest is situated within the UTM (Universal Transverse Mercator) zone 48P, with UTM coordinates of easting 411430.95 and northing 1689112.66, covering an area of 1,251,351 m^2. Waste disposal activities in the public forest began in 2012 when it was observed that community garbage was being dumped in the forest. However, prior to 2007, there was no designated waste disposal site [Figure 1 (A & B)]. In 2014, land levelling work was conducted in the waste disposal site [Figure 1 (C)]. In 2001, the waste disposal site was covered in trees and weeds [Figure 1 (D)]. For the purposes of this study, soil samples were collected at various depths of 0 cm, 20 cm, 50 cm, and 80 cm from four points within the waste disposal zone and six points in the general forest area. The waste disposal zone is represented in blue, while the general zone is in green, as shown in Figure 1 (E). Each soil sample weighed approximately 200 grams and was thoroughly mixed before being placed in a polypropylene bag. These samples were stored in an icebox before transportation to the laboratory. In addition, to soil samples, mushrooms were collected from the community, specifically from both the waste disposal zone and the general forest area during the rainy season from July 22 to 24, 2022. These mushroom samples were placed in polypropylene bags and stored in an icebox before being sent to the laboratory. It is important to note that this study focuses on naturally occurring mushrooms within the Nong-Aung public forest, meaning these mushrooms develop without human intervention. Two methods were employed to distinguish between different types of natural mushrooms: First, by consulting local villagers, and second, by referring to the Mushroom Diversity Guide (Forest and Plant Conservation Research Office, 2017) and the Mushroom Diversity Survey Manual (Forest and Plant Conservation Research Office, 2011).

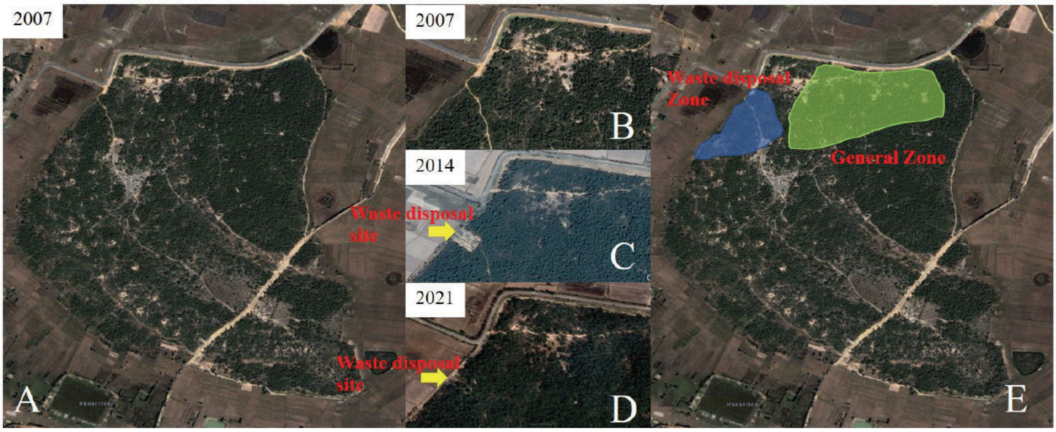


Figure 1: Study sites; (A) the public forest in 2007, (B) waste disposal site in 2007, (C) waste disposal site in 2014, (D) waste disposal site in 2021 and (E) the area of collected samples classified between the waste disposal zone and general zone

Sample Preparation

Soil samples were initially placed in plastic bags and stored in a refrigerator. Subsequently, the soil was subjected to a 72-hour drying process in a hot air oven set at 105°C. Once thoroughly dried, the soil was crushed using a mortar and pestle. A portion of the sifted soil, specifically Net No. 20, was then stored in a refrigerator at a temperature of 4°C.

For the ICP-OES analysis, a 2-gramme soil sample was used, along with concentrated hydrofluoric acid (HF), concentrated perchloric acid (HClO4), and concentrated nitric acid (HNO3), all in a 1:1:1 ratio and with a total volume of 20 ml. This mixture was subjected to extraction at 500°C using the SpeedDigester K-425 from BUCHI (Switzerland) until it became dry. Any remaining residue was thoroughly rinsed with a 1% HNO3 solution and then filtered through filter paper. The resulting supernatant was transferred to a 50 ml volumetric flask, and 1% HNO3 was added, following the procedures outlined by the United States Environmental Protection Agency (1996) and Galal *et al.* (2021). The analysis was conducted using the inductively coupled plasma (ICP) technique with a PlasmaQuant 9100 series instrument from Germany. The analysis of nitrogen and carbon, derived from total nitrogen (TN) and total carbon (TC) in the samples, was performed using the CHN-628 CHN series LECO analyser from the United States. For available soil phosphorus (P), the Bray II method (Bray & Kurtz, 1945; Wuenscher *et al.*, 2015) was employed, and the measurement was conducted using spectrophotometers at a wavelength of 882 nm.

The mushroom samples were dried for 120 hours in a 45°C hot air oven. They were then crushed with a mortar and pestle to ensure that all components of the mushrooms were utilised for the study's samples. For the mushroom element analysis, 1 g of the mushroom sample was soaked in 10 ml of concentrated nitric acid (HNO_3) in a beaker for 24 hours. Subsequently, 10 ml of a mixture containing concentrated hydrofluoric acid (HF), concentrated perchloric acid ($HCLO_4$), and concentrated nitric acid (HNO_3), with a ratio of 1:1:1, were added (Thummahitsakul *et al.*, 2018). This mixture was then subjected to extraction at 500°C using the SpeedDigester K-425 BUCHI from Switzerland until it was completely dry. The resulting residue was rinsed with 1% HNO_3 and sieved through filter paper. The supernatant was transferred to a 20 ml volumetric flask, and 1% HNO_3 was added. The continued inductively coupled plasma (ICP) technique, carried out with a PlasmaQuant 9100 series from Germany, was then used for analysis. The study's results meet the quality control standards, and the recovery rates for heavy metals range from 70% to 125%.

Quality assurance and quality control (QA/QC) procedures were implemented to ensure that all 48 samples, including duplicates and blanks, were collected, processed, and examined in the laboratory. Additionally, an ICP multielement standard solution from AccuStandard (USA) was used for comparison. After every fifteen soil samples, an ICP-OEM blank and a quality control sample were included in the analysis. This process was repeated using replicated material to maintain consistency and accuracy.

Statistical Analysis

The t-test was used to compare the components of the waste disposal zone and the general disposal zone. The one-way analysis of variance (ANOVA) was conducted to analyse the variances between groups. Differences in data sets were compared using the least significant difference (LSD) test, with a significance level of $p < 0.05$. Furthermore, Pearson's correlation analysis ($p < 0.05$) was employed. All statistical analyses were conducted using the Statistical Package for Social Science (SPSS) v.22.

Results and Discussion

Soil Properties of the Public Forest

In this section, soil conditions at four depth levels (0 cm, 20 cm, 50 cm, and 80 cm) are examined. The indicators considered included soil moisture, soil pH, bulk density, percentage of water soluble sodium chloride (NaCl), soil organic carbon, soil organic matter, total nitrogen, phosphorus available, and total potassium Soil moisture was significantly higher near the waste disposal zone compared to the general zone of the public forest area ($p < 0.01$) (Table 1), with moisture decreasing at greater depths [Figure 2 (A)]. Soil pH was higher in the general zone compared to the waste disposal zone ($p < 0.05$) across all soil layers, which is presented in Figure 2 (B). The percentage of water-soluble NaCl (between general zone and waste disposal zone) showed significant differences ($p < 0.01$) only in the top soil layer (0 cm), but insignificant in other deeper layers, which is presented in Table 1 and Figure 2 (C). The bulk density was significantly higher in the waste disposal zone compared to the general zone ($p < 0.05$) in all soil layers, which is presented in Figure 2 (D). There were no significant differences in soil organic carbon and organic matter between the two zones, which is presented in Table 1. Total nitrogen in the 50 cm and 80 cm layers was significantly higher in the general zone (p < 0.01), while no significant differences were observed in the top soil (0 cm) and 20 cm layers, which is presented in Table 1. The total nitrogen in the soil layer [Figure 2 (G)] and the amount of available phosphorus in the soil in the general zone is different ($p < 0.05$) from the quantities in the waste disposal zone (Table 1). The quantity of phosphorus available in the public forest area is not significant. Phosphorus is available in high quantities in the top layer of soil and decreases based on the soil layer [Figure 2 (H)]. Total potassium content in the waste disposal zone was significantly different from that in the general zone ($p < 0.05$), which is presented in Table 1, with an increase in total potassium content with increasing soil depth., presented in Figure 2 (I).

Heavy Metal Content in the Soil

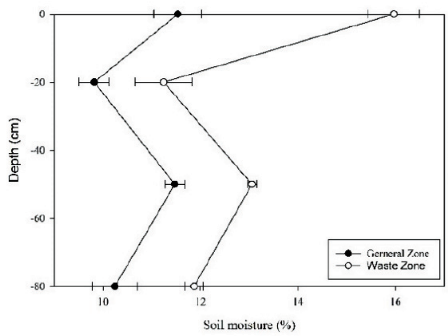
In the soil surface layer, the waste disposal zone exhibited higher quantities of Al, Cd, Cu, Pb, and Ni compared to the general zone, and these differences were statistically significant ($p < 0.05$). However, the quantities of Mn and As in the top soil layer did not show significant differences between the general and waste disposal zones (Table 2). In the 20 cm deep soil layer, Pb content in the waste disposal zone (18.8 ± 3.41 mg/kg) was significantly higher ($p < 0.05$) than in the general zone (15.6 ± 1.90 mg/kg), while Mn content was higher in the general zone and exhibited statistical significance ($p < 0.05$) compared with the waste disposal zone (43.9 ± 12.1 to 38.9 ± 8.50). The quantities of Al, Cd, Cu, Ni, and As in the 20 cm deep soil layer did not differ significantly between the

Table 1: The soil properties of the Nong-Aung public forest (general zone and waste disposal zone) based on soil layer

Indicators		General Zone	Waste Disposal Zone	Sig. (2-tailed)
Soil surface				
Soil moisture (%)		11.5 ± 1.20	15.9 ± 1.30	.001
	Range	2.75	3.43	
Soil pH		5.60 ± 0.599	4.31 ± 0.649	.010
	Range	1.61	1.76	
NaCl water soluble (%)		0.070 ± 0.010	0.018 ± 0.009	.000
	Range	0.02	0.02	
Bulk density (g/cm^3)		0.704 ± 0.142	1.03 ± 0.238	.002
	Range	0.377	0.525	
Soil organic carbon (mg/kg)		355 ± 170	565 ± 159	ns
	Range	351	307	
Soil organic matter (mg/kg)		12271 ± 5882	19500 ± 5516	ns
	Range	12133	10594	
Total nitrogen (mg/kg)		0.395 ± 0.148	0.702 ± 0.264	ns
	Range	0.370	0.545	
Phosphorus available (mg/kg)		30.5 ± 16.5	6.75 ± 1.81	.010
	Range	46.1	1.33	
Total potassium (mg/kg)		1877 ± 255	4852 ± 1620	.011
	Range	605	3220	
A depth of 20 cm below the soil's surface				
Soil moisture (%)		9.81 ± 0.754	11.2 ± 1.42	ns
	Range	1.77	3.84	
Soil pH		5.74 ± 0.133	4.16 ± 0.536	.001
	Range	0.34	1.4	
NaCl water soluble (%)		0.050 ± 0.034	0.015 ± 0.005	ns
	Range	0.08	0.01	
Bulk density (g/cm^3)		0.613 ± 0.100	0.802 ± 0.256	ns
	Range	0.266	0.692	
Soil organic carbon (mg/kg)		10.2 ± 11.2	5.85 ± 6.07	ns
	Range	22.2	12.3	
Soil organic matter (mg/kg)		354 ± 387	201 ± 209	ns
	Range	766	425	
Total nitrogen (mg/kg)		0.230 ± 0.031	0.177 ± 0.039	ns
	Range	0.068	0.084	
Phosphorus available (mg/kg)		8.11 ± 7.89	2.93 ± 1.89	ns
	Range	19.7	5.14	
Total potassium (mg/kg)		2171 ± 135	9207 ± 1313	ns
	Range	316	3240	

A depth of 50 cm below the soil's surface				
Soil moisture (%)		11.47 ± 0.500	13.05 ± 0.225	.000
	Range	1.22	0.612	
Soil pH		5.60 ± 0.265	3.91 ± 0.489	.001
	Range	0.660	1.3	
NaCl water soluble (%)		0.060 ± 0.048	0.016 ± 0.005	ns
	Range	0.110	0.010	
Bulk density (g/cm^3)		0.613 ± 0.126	0.979 ± 0.179	.031
	Range	0.270	0.496	
Soil organic carbon (mg/kg)		8.60 ± 9.22	7.11 ± 7.38	ns
	Range	17.8	14.1	
Soil organic matter (mg/kg)		296 ± 318	245 ± 254	ns
	Range	615	488	
Total nitrogen (mg/kg)		0.315 ± 0.063	0.180 ± 0.037	.000
	Range	0.14	0.078	
Phosphorus available (mg/kg)		6.27 ± 4.96	2.06 ± 0.074	ns
	Range	12	0.203	
Total potassium (mg/kg)		3008 ± 208	5214 ± 509	.046
	Range	5361	1217	
A depth of 80 cm below the soil's surface				
Soil moisture (%)		10.2 ± 1.13	11.8 ± 0.463	.000
	Range	0.461	0.189	
Soil pH		5.61 ± 0.240	3.91 ± 0.463	.000
	Range	0.098	0.161	
NaCl water soluble (%)		0.040 ± 0.028	0.015 ± 0.396	ns
	Range	0.011	0.002	
Bulk density (g/cm^3)		0.535 ± 0.048	0.745 ± 0.172	.043
	Range	0.019	0.07	
Soil organic carbon (mg/kg)		9.11 ± 9.63	2.93 ± 3.07	ns
	Range	3.93	1.15	
Soil organic matter (mg/kg)		314 ± 332	101 ± 106	ns
	Range	135	43.3	
Total nitrogen (mg/kg)		0.214 ± 0.020	0.180 ± 0.024	.006
	Range	0.008	0.01	
Phosphorus available (mg/kg)		6.53 ± 8.24	2.17 ± 0.085	ns
	Range	3.36	0.034	
Total potassium (mg/kg)		2946 ± 86.3	6109 ± 77.2	.000
	Range	35.2	77.2	

Note: t-test pairs = criteria p-value 95% ($p < 0.05$); ns=not significant ($p > 0.05$)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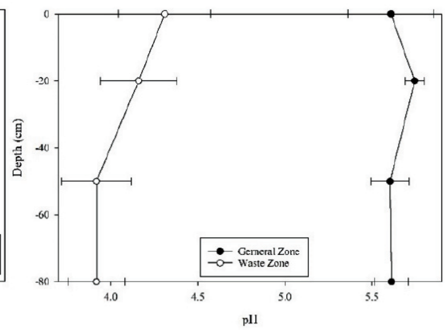
Waste Zone

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pH
Gerneral Zone
Waste Zone

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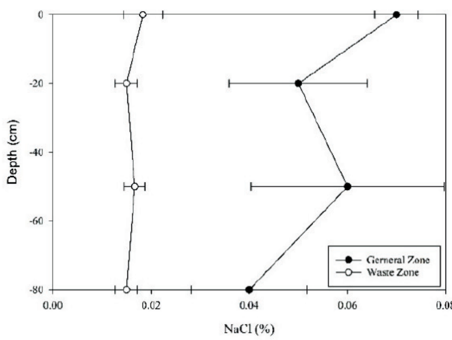
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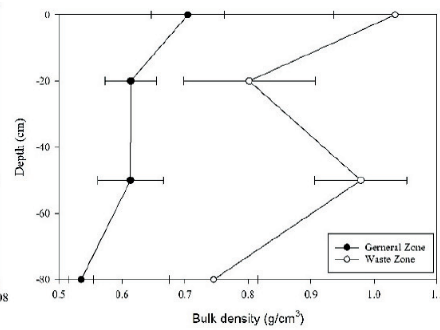
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Bulk density (g/cm3)
General Zone
Waste Zone

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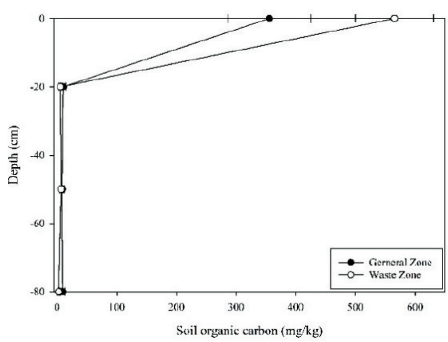
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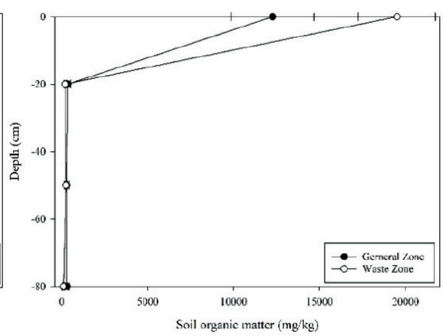
Depth (cm)
Soil organic matter (mg/kg)
Gerneral Zone
Waste Zone

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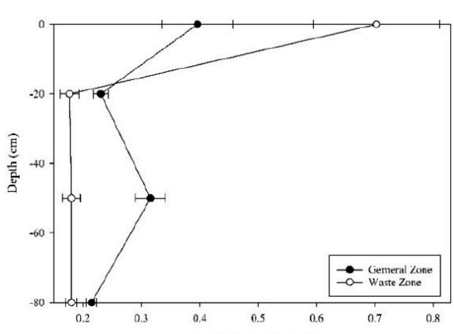
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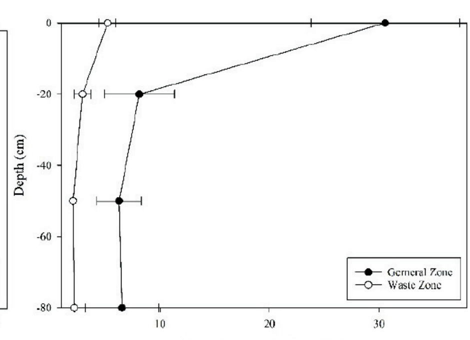
Waste Zone

Depth (cm)
Phosphorus available (mg/kg)
Gerneral Zone
Waste Zone

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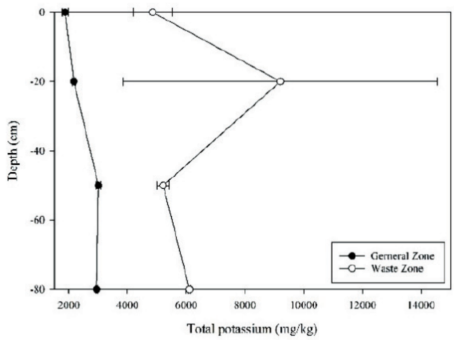

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Figure 2: The trend of soil properties in the general zone and waste disposal zones in the Nong-Aung public forest based on the soil layer. (A) percentage of soil moisture, (B) soil pH, (C) percentage of water-soluble NaCl, (D) bulk density, (E) soil organic carbon, (F) soil organic matter, (G) total nitrogen in soil, (H) phosphorus available in the soil, and (I) total potassium in the soil

general and waste disposal zones. In the 50 cm deep soil layer, Cu content in the waste disposal zone (27.4 ± 18.4 mg/kg) was significantly higher ($p < 0.05$) than in the general zone (15.6 ± 1.90 mg/kg). The quantities of Al, Cd, Pb, Mn, Ni, and As in both zones did not show significant differences. In the 80 cm deep soil layer, the quantities of Al, Ni, and As were not significantly different between the general zone and the waste disposal zone. However, Cd, Cu, and Ni content in the soil of the waste disposal zone were significantly higher ($p < 0.05$) than in the general zone. Pb content in the general zone (15 ± 2.33) was also significantly higher ($p < 0.05$) than in the waste disposal zone (6.97 ± 2.93 mg/kg). A summary of the heavy metal quantities in the general and waste disposal zones is presented in Table 2, and the trends of heavy metal distribution in soil layers in both zones are illustrated in Figure 3.

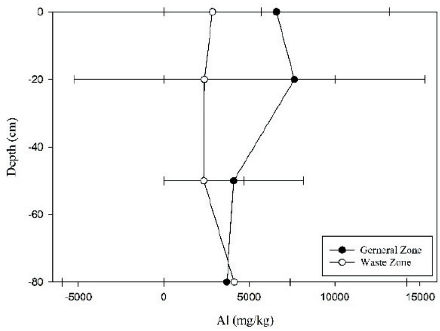
Table 2: The heavy metal contents in the soil from the Nong-Aung public forest in the general and waste disposal zones based on soil layer

Element	General Zone	Waste Disposal Zone	Sig. (2-tailed)
Soil surface			
Al	32046 ± 16145	49129 ± 6971	0.045
Range	44661	16462	
Cd	1.78 ± 0.046	2.43 ± 0.548	0.033
Range	0.122	1.34	
Cu	14.1 ± 7.12	46.2 ± 25.1	0.058
Range	13.5	48.1	
Pb	12.6 ± 0.099	20.6 ± 1.64	0.000
Range	0.257	3.42	
Mn	125 ± 78.1	326 ± 201	ns
Range	146	391	
Ni	19.1 ± 3.41	43.5 ± 13.6	0.002
Range	6.36	25.3	
As	0.011 ± 0.002	0.011 ± 0.002	ns
Range	0.005	0.005	

A depth of 20 cm below the soil's surface			
Al	40758 ± 18714	29466 ± 5816	ns
Range	35422	11467	
Cd	1.80 ± 0.098	1.72 ± 0.065	ns
Range	0.264	0.182	
Cu	15 ± 1.90	11.7 ± 3.16	ns
Range	13.9	7.79	
Pb	15.6 ± 1.90	18.8 ± 3.41	0.005
Range	4.02	6.37	
Mn	43.9 ± 12.1	38.9 ± 8.50	0.021
Range	22.2	16.5	
Ni	23 ± 2.36	20.1 ± 0.917	ns
Range	4.86	2.01	
As	0.009 ± 0.001	0.010 ± 0.000	ns
Range	0.003	0.001	
A depth of 50 cm below the soil's surface			
Al	48014 ± 10011	51197 ± 5731	ns
Range	19456	12079	
Cd	1.82 ± 0.289	1.92 ± 0.173	ns
Range	0.697	0.422	
Cu	19.1 ± 15.9	27.4 ± 18.4	0.000
Range	29.8	35	
Pb	13.2 ± 3.72	11.2 ± 6.77	ns
Range	7.85	12.8	
Mn	49.1 ± 28.3	85.1 ± 60.9	ns
Range	52	112	
Ni	21.8 ± 16.2	39.8 ± 27.1	ns
Range	30.6	50.3	
As	0.008 ± 0.000	0.013 ± 0.010	ns
Range	0.002	0.02	
A depth of 80 cm below the soil's surface			
Al	48954 ± 9043	48689 ± 10078	ns
Range	17425	19601	
Cd	1.78 ± 0.072	1.92 ± 0.128	0.005
Range	0.172	0.287	
Cu	16.8 ± 10.7	25.9 ± 16.4	0.011
Range	20.3	30.6	
Pb	15 ± 2.33	6.97 ± 2.93	0.013
Range	4.55	5.91	
Mn	68.3 ± 42	117 ± 80.4	ns
Range	79.4	148	

Ni	17.6 ± 10.5	43.5 ± 28.1	0.016
Range	19.4	54.9	
As	0.008 ± 0.001	0.007 ± 0.000	ns
Range	0.004	0.002	

Note: t-test pairs = criteria *p*-value 95% ($p < 0.05$); ns = not significant ($p > 0.05$)



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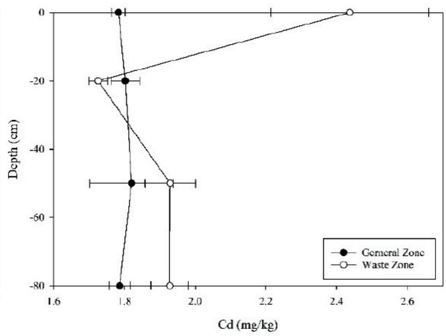

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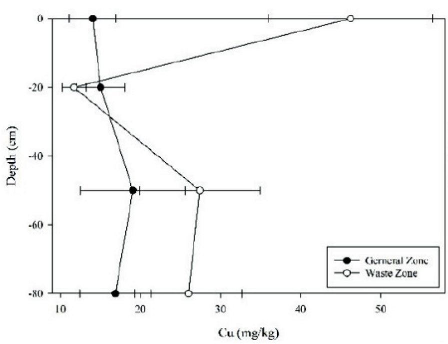

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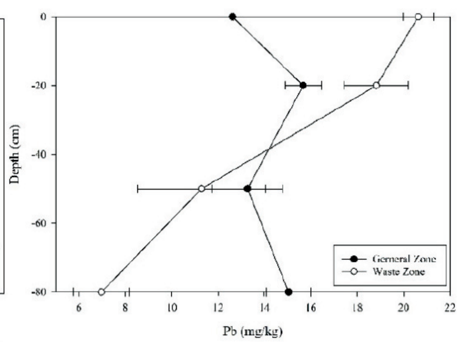

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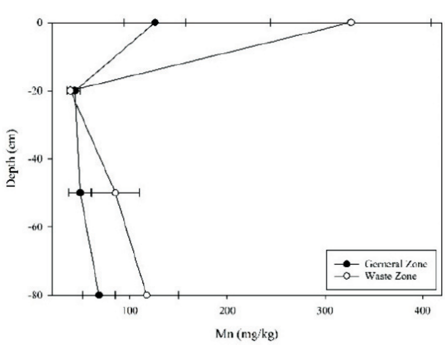

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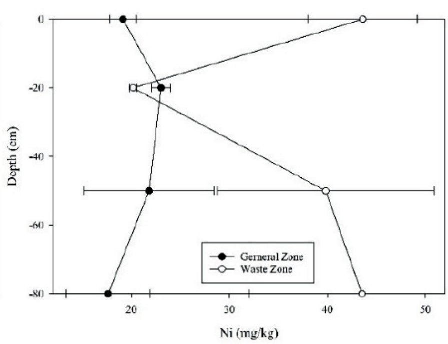

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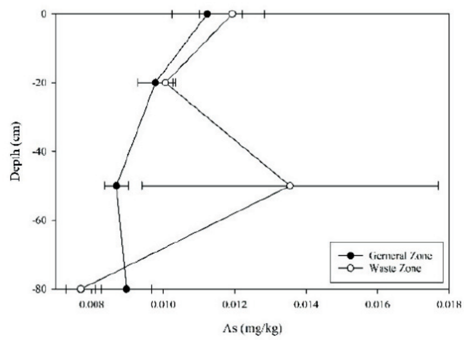

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Figure 3: The dynamics of heavy metals in the general and the waste disposal zones in the Nong-Aung public forest based on soil layer

The Long-term Effect of Waste in the Disposal Area

The soil condition in the waste disposal area and the general zone differs significantly in three main aspects: Soil pH, bulk density, and total potassium. Notably, the soil pH data in the waste disposal zone is inversely correlated with As content (r = -0.832; $p < 0.05$), indicating that higher As levels are associated with lower pH values. This decrease in pH near the waste disposal zone might be attributed to the accumulation of garbage over an extended period. Furthermore, the research identified a substantial variation in the pH of the topsoil between the general and disposal zones ($p <$ 0.01). This variation is related to the levels of phosphorus and potassium in the soil (Vasak *et al.*, 2015), and the presence of aluminium (Al), which can influence soil pH (Fontes & Alleoni, 2006). It is possible that ion exchange processes are occurring, involving substances like calcium carbonate reacting with water to form hydroxyl ions (OH-) or the oxidation of organic sulfur (S) to sulfate ions (SO42-), possibly accompanied by hydrogen ions (H+) (Freedman, 1995; Sparks, 2003). These reactions may be attributed to the decomposition of waste, especially organic waste in the waste disposal zone within the public forest. Consequently, waste disposal has had a direct and significant impact on soil pH over the past 8 to 10 years, with potential consequences for regional biodiversity.

The Heavy Metal in the Waste Disposal Area

The heavy metal content in the waste disposal zone can vary depending on different elements. For instance, the quantity of potassium (K) is linked to the levels of Cd and mercury (Hg). Soil pH, on the other hand, is associated with the amounts of Pb, N, and Se in acidic soil conditions (Kroeksakul *et al.*, 2021). The percentage of soil moisture is directly related to the movement of mercury (Hg) from underground to the soil surface (Shi *et al.*, 2019). These variations in heavy metal quantities have repercussions on the soil characteristics within the waste disposal zone. When comparing the waste disposal zone to the general area of the public forest, the soil in the former has a lower pH value and higher moisture content. In this study, the levels of Al, Cd, Cu, Pb, and Ni in the waste disposal zone are significantly higher ($p < 0.05$) than in the general zone. This difference may be attributed to processes such as waste decomposition or composting. Additionally, the mineralisation of raw materials, such as plastic or glass, can release Al, Cu, Fe, Ni, and Pb into the environment (Ciavatta *et al.*, 1993; Tella *et al.*, 2013; Kinuthia *et al.*, 2020). Heavy metals like Cu, Zn, Cd, As, Hg, and Pb can also be released from organic waste (Lopes *et al.*, 2011; Borjac *et al.*, 2019; da Silva *et al.*, 2020). However, it is important to note that the quantities of heavy metals in the waste disposal zone of the Nong-Aung public forest do not exceed Thailand's standards. These standards are as follows: Cd < 67 mg/kg, Mn < 1.7 g/kg, Ni < 140.4 mg/kg, Pb < 400 mg/kg, and As < 3.9 mg/kg (Pollution Control Department, 2009).

The Heavy Metal Content in the Natural Mushroom

In this study, the species collected in the waste disposal zone include the Hed Ham-Fan, which is the local name for *Mycoamaranthus cambodgensis* (Pat.) Trap, and the Hed Chin-Yang, which is the local name for *Ganoderma applanatum* (Pers.ex Wallr.) Patouillard. These mushrooms are depicted in Figure 4 (A). In the general zone, the Hed Pieng-Dang, which is the local name for *Heimioporus japonicus* (Hongo) E. Horak, and the Hed Tub-tao, which is the local name for *Thaeogyroporus porentosus* (berk. ET. Broome), were found. The characteristics of these mushrooms are presented in Figure 4. The moisture content in the mushrooms averages 69.55 ± 16.45% for fresh weight. The average quantity of Cd in the mushrooms is 0.5581 ± 0.9081 mg/kg (dry weight), while Pb has an average content of 1.740 ± 2.441 mg/kg (dry weight). Mn content in the mushrooms averages 266 ± 128 mg/kg (dry weight), Ni content averages 4.445 ± 2.837 mg/kg (dry weight), and As content averages 0.0143 ± 0.0058 mg/kg (dry weight). However, it is important to note that the quantity of heavy metals in the mushrooms varies depending on the species, and this variation is detailed in Table 3.

Figure 4: The natural mushroom collected for analysis; (A) the local name is Hed Ham-Fan (*Mycoamaranthus cambodgensis* (Pat.) Trap), (B) the local name is Hed Chin-Yang (*Ganoderma applanatum* (Pers.ex Wallr.) Patouillard), (C) the local name is Hed Pieng-Dang (*Heimioporus japonicus* (Hongo) E. Horak), (D) the local name is Hed Tub-tao (*Thaeogyroporus porentosus* (berk. ET. Broome), and (E) the total mushrooms that can be used for cooking

Table 3: The moisture and element content of a mushroom

Component	Samples	Element Content (mg/kg)
Moisture (%)	A	69.40 ± 0.855^{a}
	B	32.8 ± 2.54^{b}
	C	74.8 ± 9.33^{ac}
	D	77.2 ± 2.77^{ac}
	E	80.5 ± 1.74^{c}
	Average	69.5 ± 16.4
Cd (mg/kg)	A	0.012 ± 0.002^{a}
	B	0.020 ± 0.004^{a}
	C	0.007 ± 0.007^{a}
	D	1.89 ± 0.555^{b}
	E	0.075 ± 0.007^{a}
	Average	0.558 ± 0.908

Pb (mg/kg)	A	0.004 ± 0.000[a]
	B	0.019 ± 0.005[a]
	C	0.806 ± 0.605[a]
	D	3.96 ± 3.52[b]
	E	2.61 ± 0.280[ab]
	Average	1.74 ± 2.44
Mn (mg/kg)	A	107 ± 1.28[a]
	B	308 ± 1.15[b]
	C	230 ± 61.3[ab]
	D	332 ± 194[b]
	E	323 ± 2.79[b]
	Average	266 ± 128
Ni (mg/kg)	A	0.535 ± 0.106[ac]
	B	5.95 ± 0.521[bc]
	C	3.72 ± 1.64[abc]
	D	4.73 ± 3.36[bc]
	E	7.71 ± 1.02[b]
	Average	4.44 ± 2.83
As (mg/kg)	A	0.021 ± 0.000[ac]
	B	0.010 ± 0.000[b]
	C	0.018 ± 0.005[ac]
	D	0.008 ± 0.002[b]
	E	0.014 ± 0.000[bc]
	Average	0.014 ± 0.005

Note: [abcd] The mean in column differences is significant at the p-value < 0.05 level (LSD); (A) the local name is Hed Ham-Fan [*Mycoamaranthus cambodgensis* (Pat.) Trap], (B) the local name is Hed Chin-Yang [*Ganoderma applanatum* (Pers.ex Wallr.) Patouillard], (C) the local name is Hed Pieng-Dang [*Heimioporus japonicus* (Hongo) E. Horak], (D) the local name is Hed Tub-tao [*Thaeogyroporus porentosus* (berk. ET. Broome)] and € the total mushrooms that can be used for cooking

The Quantity of Heavy metal in the Mushroom between Waste Disposal Zone and General Zone

Table 3 demonstrates that the heavy metal content varies among different mushroom species. A comparison is made between the metal content in mushrooms from the waste disposal zone and those from the general zone. Interestingly, there is not a significant difference in the moisture content of mushrooms from both zones. Notably, the differences in quantities of Cd, Mn, and Ni between the waste disposal area and the general area are not significant. However, Pb and As contents were found to be more significant in the general zone than in the waste disposal zone. It is important to acknowledge that while this study observes these differences, several factors can influence element content, such as mushroom species or substrate origin, as indicated in previous research (Dowlati *et al.*, 2021; Dong *et al.*, 2022). The values are detailed in Table 4.

Crucially, the quantity of heavy metals in the mushrooms does not exceed the standards for heavy metal contamination in food established by the Notification of Ministry of Public Health (No. 98) B.E. 2529 (1986). These standards include limits such as Cu < 20 mg/kg and Pb

Table 4: Comparison of the components of the mushrooms in the waste disposal zone and the general zone of the Nong-Aung public forest

Indicators	Waste Disposal Zone	General Zone	Sig. (2-tailed)
Moisture (%)	51.1 ± 20	74.8 ± 9.33	0.105
Cd (mg/kg of dry weight)	0.016 ± 0.005	0.007 ± 0.007	0.131
Pb (mg/kg of dry weight)	0.012 ± 0.008	0.806 ± 0.605	0.023
Mn (mg/kg of dry weight)	208 ± 110	230 ± 61.3	0.318
Ni (mg/kg of dry weight)	3.24 ± 2.98	3.74 ± 1.64	0.516
As (mg/kg of dry weight)	0.015 ± 0.005	0.018 ± 0.005	0.002

Note: Cd = cadmium, Pb = lead, Mn = manganese, Ni = nickel, and As = arsenic

< 1 mg/kg. Food that contains a high level of natural lead must be approved by the Office Food and Drug Administration. Another limit is As < 2 mg/kg (Ministry of Public Health, 2022). Thus, the metal content of the mushrooms in the Nong-Aung public forest is within acceptable limits and does not surpass the standard.

The Correlation between Heavy Metal Content in Soil and Natural Mushrooms

The correlation between the amount of heavy metal in the soil and the natural mushrooms was tested using the Pearson's correlation coefficient. The Cd content in soil is negatively correlated with the Cd content in the mushrooms (r = -0.856; $p < 0.01$); there is a positive correlation with the quantity of Pb in the mushroom (r = 0.931; $p < 0.01$). The Cu content in soil is negatively correlated with the Cd content in the mushroom (r = -0.947; $p < 0.01$); it is positively correlated with Pb in the mushroom (r = 0.970; $p < 0.01$) and Cd quantity in the soil (r = 0.943; $p < 0.01$). The Pb content in soil is negatively correlated with the amount of Cd in the mushroom (r = -0.759; $p < 0.01$) and positively correlated with the Pb content in the mushroom (r = 0.861; $p < 0.01$). The combined Cd and Cu content in the soil (r = 0.834, r = 0.846; $p < 0.01$) and the Mn content in the soil have a negative correlation to the quantity of Cd in the mushroom (r = -0.954; $p < 0.01$); they have a positive correlation with the Pb content in the mushroom (r = 0.932; $p < 0.01$), Cd in soil (r = 0.919; $p < 0.01$), Cu in soil (r = 0.987; $p < 0.01$), and Pb in soil (r = 0.760; $p < 0.01$). The amount of Ni in soil has a negative correlation with the Cd content in the mushroom (r = -0.811; $p < 0.01$) and a positive correlation with the Pb content in the mushroom (r = 0.973; $p < 0.01$), Cd content in soil (r = 0.932; $p < 0.01$), Cu content in soil (r = 0.928; $p < 0.01$), Pb content in soil (r = 0.921; $p < 0.01$), and Mn content in soil (r = 0.864; $p < 0.01$). The amount of As in soil is negatively correlated with the Mn content in the mushroom (r = -0.891; $p < 0.01$) and the Ni content in the mushroom (r = -0.876; $p < 0.01$); it is positively correlated with the quantity of As in the mushroom (r = 0.962; $p < 0.01$). The correlation between heavy metal content in soil and mushrooms is presented in Table 5. However, the amount of heavy metals in mushrooms, particularly Pb, Cd, and As, is connected to the source soil substrate (Kokkoris *et al.,* 2019; Zoysa *et al.*, 2020). Furthermore, some heavy metals, including Fe and Cu, build up in mushrooms more so than in the soil substrate (Semreen & Aboul-Enein, 2011; Gebrelibanos *et al.,* 2016).

Factors of Heavy Metal Components in the Mushroom and Soil

Principal Component Analysis (PCA) was employed to analyse the parameters of the 12 components in both the mushrooms and soil. Three principal components (PCs) were identified, each with an eigenvalue exceeding 1, collectively explaining 96.18% of the cumulative data (see Table 6). Notably, PC1 accounted for the highest variance (57.05%), followed by PC2 (30.40%) [refer Table 7 and

Table 5: Correlation between heavy metal content in soil and natural mushrooms

	MCd	MPb	MMn	MNi	MAs	SAl
MCd	1					
MPb	0.371	1				
MMn	0.115	.865**	1			
MNi	-0.091	.658**	.896**	1		
MAs	-.574**	-.618**	-.723**	-.618**	1	
SAl	-0.160	0.213	-0.137	-0.116	0.450	1
SCd	-.856**	.931**	0.410	0.357	-0.192	0.220
SCu	-.947**	.970**	0.257	0.208	-0.082	0.229
SPb	-.759**	.861**	0.244	0.205	0.144	0.508
SMn	-.954**	.932**	0.190	0.135	-0.083	0.147
SNi	-.811**	.973**	0.512	0.459	-0.220	0.293
SAs	0.051	-0.296	-.891**	-.876**	.962**	0.385
	SCd	**SCu**	**SPb**	**SMn**	**SNi**	**SAs**
SCd	1					
SCu	.943**	1				
SPb	.834**	.846**	1			
SMn	.919**	.987**	.760**	1		
SNi	.932**	.928**	.921**	.864**	1	
SAs	-0.283	-0.175	0.008	-0.163	-0.329	1

Note: **Correlation is significant at the 0.01 level (2-tailed); MCd = cadmium content in mushroom; MPb = lead content in mushroom; MMn = manganese content in mushroom; MNi = nickel content in mushroom; MAs = arsenic content in mushroom; SAl = aluminium content in soil; SCd = cadmium content in soil; SPb = lead content in soil; SMn = manganese content in soil; SNi = nickel content in soil; SAs = arsenic content in soil.

Figure 5 (A)]. In this analysis, Cu content in the soil emerged as the most significant contributor with a factor load of 0.991, making it the primary loading factor. The second factor load highlighted the importance of Mn content in the soil (0.985), as well as the Pb content in the mushrooms (0.946), and the cadmium content in the soil (0.930). Moving on to PC2, the nickel content in the mushrooms was identified as the most influential contributor (0.972), closely followed by Mn content in the mushrooms (0.970). This relationship between eigenvalues, components in the principal analysis, and the component loading of PCs is visually presented in Figure 5 (B).

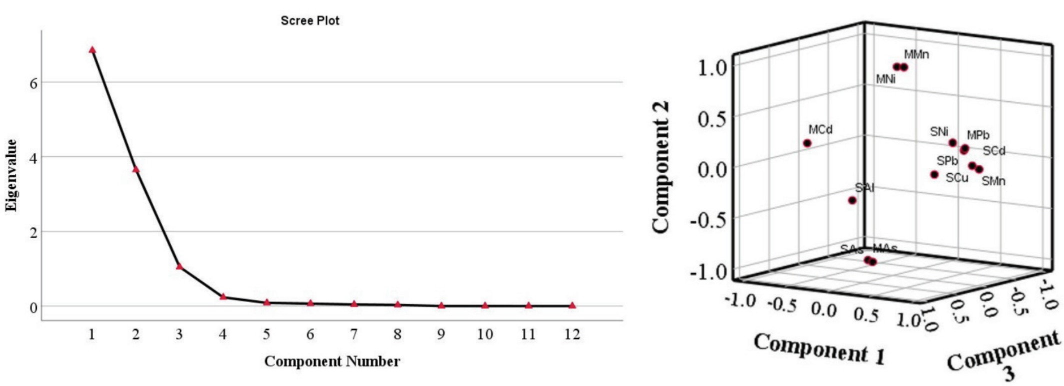
Performance of Mushroom as Bioindicators of Heavy Metal

The analysis has revealed a positive correlation between the presence of As in soil and its presence in mushrooms ($r = 0.962$; $p < 0.01$), as well as a similar correlation between the quantity of Pb in soil and its presence in mushrooms ($r = 0.861$; $p < 0.01$), which aligns with the findings in PCA components 1 and 3 [refer Figure 5 (A)]. It is worth noting that mushrooms have limitations in storing certain heavy metals, including Fe, Cd, Zn, Cr, Hg, and Ni, as supported by previous research (Swislowski & Rajfur, 2018; Ediriweera *et al.*, 2022). The storage of heavy metals by mushrooms can impact various soil properties, both physico chemical and biological, as well as the overall environment (Medina *et al.*, 2012; Tan *et al.*,

Table 6: Results from the PCA of the statistically significant metal content in the soil and mushrooms in the public forest

PCs	Component		
	PC1	PC2	PC3
Percentage of Variance (%)	57.0	30.4	8.72
Cumulative (%)	57.0	87.4	96.1
Eigenvalue	6.84	3.64	1.04
MCd	-.970	.102	.057
MPb	.946	.255	.128
MMn	.186	.970	.075
MNi	.126	.972	.106
MAs	-.018	-.934	.314
SAl	.167	-.221	.920
SCd	.930	.232	.125
SCu	.991	.080	.070
SPb	.833	.038	.484
SMn	.985	.026	-.053
SNi	.898	.325	.267
SAs	-.114	-.934	.253

Note: PC = Principal component; underlined factor loading is weighted higher when within 10% of the variation of the absolute value of the highest factor loading in each PC; MCd = cadmium content in mushroom; MPb = lead content in mushroom; MMn = manganese content in mushroom; MNi = nickel content in mushroom; Mas = arsenic content in mushroom; Sal = aluminium content in soil; SCd = cadmium content in soil; SPb = lead content in soil; SMn = manganese content in soil; SNi = nickel content in soil; SAs = arsenic content in soil.



(A) (B)

Figure 5: Results of the PCA of heavy metal content in the soil and the mushrooms: (A) the eigenvalue of components in the principal analysis; (B) the component loading of PCs (PC1 SCu > SMn > MPb > SCd > SAs, PC2 is MNi > MMn)

2021; Joniec *et al.*, 2022). However, mushrooms can serve as effective bioindicators for assessing heavy metal pollution in the environment. It is crucial to emphasise that mushrooms are a vital food source for villagers, underscoring the importance of raising awareness about environmental factors and the nutritional quality of mushrooms. A safe and stable environment not only contributes to higher-quality mushrooms but also ensures better-quality food for the local population.

Conclusion

Over the past 8 to 10 years, villagers have established a waste disposal zone, which has brought about significant changes in various soil properties, including soil pH, bulk density, soil moisture, and potassium content. Additionally, heavy metal contaminants in the soil from the waste disposal zone differ significantly ($p < 0.05$) from those in the general zone of the public forest. These changes in both soil properties and heavy metal contamination can be attributed to land use and human activities in the area. Despite these changes, it's important to note that the quantity of heavy metals in the Nong-Aung public forest does not exceed the standards set by Thailand. Furthermore, the heavy metal content in the natural mushrooms varies depending on the species. The ranking of heavy metal content in mushrooms is as follows: Mn > Ni > Pb > Cd > As, with a ratio of 100:1.66:0.654:0.206:0.005. Importantly, the heavy metal content in mushrooms from the Nong-Aung public forest does not exceed the standards approved by the Office of Food and Drug Administration in Thailand. This study highlights that mushrooms can serve as effective indicators for assessing the presence of As and Pb in the soil. Overall, the results suggest that while the heavy metals in the soil and natural food sources are within official standards, the rapid changes in soil properties in the waste disposal zone could pose a threat to biodiversity. It is essential for the local government and citizens to take action to restrict the expansion of the waste disposal area and promote waste reduction measures.

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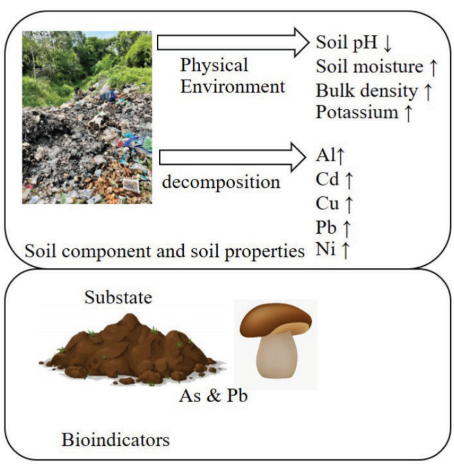

Figure 6: Waste disposal area, mushroom bioaccumulation, and heavy metal contamination in the Nong-Aung public forest

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