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ORIGINAL RESEARCH ARTICLE

Impact of heavy metal pollution on the use of fishing pond land, a former site of used battery smelting

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ABSTRACT

BACKGROUND AND OBJECTIVES: Cinangka Village in Bogor Regency is a traditional used battery recycling center in West Java, Indonesia. The smelting process was operated in open space, but because of adverse impacts, it has ceased since 2010. This activity generated a large amount of solid waste, categorized as hazardous and toxic materials, thereby polluting the air, land, and water. Because an area of Cinangka Village has been converted into a fishing pond, it is necessary to investigate whether the fish that live in this pond are accumulating heavy metals, thereby threatening and harming humans as consumers. This research is important for the innovative remediation of land contaminated with used battery smelting waste.

METHODS: Analysis of lead, zinc, arsenic, and iron levels in water, sediment, fish, and aquatic plants, as well as histomorphology analysis of several fish organs, was performed. The safety aspect of consuming fish originating from this location was also calculated. For the used battery recycling area, lead and iron contaminate the environment in the highest concentrations, while arsenic and zinc are always detected but in low concentrations.

FINDINGS: The results showed that sediment and water around the pond, previously a burning area of used battery smelting but 12 years after cessation, are polluted by heavy metals, not only lead, zinc, arsenic, and iron. Other metals are present because lead and lead oxide plates are impure and associated with other minerals. According to the lead concentration, the soil/sediment is still categorized as hazardous and toxic material and becomes a pollutant for the ecosystem. Water hyacinth plants that live in ponds are densely cultivated and contaminated with heavy metals. They can become heavy metal phytoremediators on the land where traditional used battery burning was performed. Goldfish from this area are contaminated with high levels of heavy metals and are unfortunately unsafe for consumption because zinc is perilous. Adults are only allowed 3 gram per week, while children may not consume goldfish from this fishing pond. Contaminating heavy metals also cause various damage to fish organs, namely, edema in the kidneys, melano-macrophage centers in the spleen and liver, edema and hyperplasia in the epithelial gills, and fatty degeneration in the liver and its lysed ovary cells.

CONCLUSION: Consequently, land in Cinangka Village is still categorized as hazardous, and toxic waste and should not be converted into a fishing pond because the soil is a point source of pollution that contaminates fish with high concentrations of heavy metals and damages their organs. Consuming these goldfish will harm health and thus is prohibited for children. Cleaning and remediation of the environment is necessary and must cover the entire area. Meanwhile, water hyacinth plants can be used as phytoremediators in freshwater ponds to reduce heavy metals.

NUMBER OF REFERENCES	NUMBER OF FIGURES	NUMBER OF TABLES
104	7	7

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INTRODUCTION

Clean production is a management strategy or integrated prevention through a continuous process so that minimal (to zero) waste is produced (UNEP, 2006). Clean production is used to minimize waste (Hadibarata and Chia, 2021). One way to achieve clean production is by reusing waste (Azzahro *et al.,* 2022; Ariyanti *et al*., 2014), such as used batteries. However, this approach often creates new problems because of traditional processing by the community using the direct melting method and very simple equipment in an open space. This process generates toxic and hazardous materials that are directly released into the environment (Bayuseno, 2009). Located in Cinangka Village, Bogor Regency was a used battery smelting location. Used battery smelting in Cinangka is usually operated in open space, thus generating air, water, and land pollution. The waste has become a problem because it contains a large amount of hazardous and toxic materials. Unfortunately, people were unaware of this toxicity; the waste was even used as concrete-mix material for roads and buildings, as well as field, river, and pond embankments. People who live in this area began to know each other after socialization was carried out in 2010. However, the field observations conducted by the author indicate that these people still lack concern about the dangers. Therefore, after the area closed for business, some people continued to stockpile waste because of the high cost of waste processing. For example, at one waste processing company, the cost per metric ton of waste was United States dollar (USD) 316 (excluding the shipping cost). Consequently, they still dispose of the waste in the environment despite knowing about the danger. Moreover, the former smelting area has been converted into fishponds intended for cultivating ornamental fish. Unfortunately, we found one fishpond that was converted into a fish farm and fishing pond. Hazardous and toxic material waste originating from used battery smelting activities contains various types of heavy and light metals, ammonia, chlorine, and other toxic compounds. According to research by Oloruntoba *et al.* (2021), at a used lead-acid battery recycling center in Nigeria, not only Pb was detected but also other types of heavy metals such as arsenic (As), cadmium (Cd), antimony (Sb), chromium (Cr), copper (Cu), magnesium (Mn), nickel (Ni), selenium (Se), and zinc (Zn). Their smelting process also generates air pollution. With dry and wet deposition, air pollutants enter the soil and groundwater. Pollutants already on the ground will be run off by rain and enter the aquatic ecosystem. At the time of the survey, the condition appeared to be worsening because of the large amount of battery waste used to harden roads and reinforce walls. Contamination on land and water is also high. Heavy metals are not degraded through microbial activity but are persistent and accumulate in soil, water, and sediment through deposition, leaching, and erosion (Majumder *et al.,* 2021). Heavy metals and light metals are generally irreversible if bound to body organs (Ali and Khan, 2018), and they accumulate in the bodies of living creatures (Briffa *et al.,* 2020), including plants (Zulfiqar *et al.,* 2019) and even humans (O'shea *et al.,* 2021). Accumulated heavy metals can damage various organs, such as the kidneys (Komoike and Matsuoka 2022; Naz *et al.,* 2023), and weaken immunity (Giri *et al.,* 2021; Aranda-Rivera *et al.,* 2022). Soil and sediment present similar conditions and will also accumulate hazardous and toxic materials (Ali *et al.,* 2019; Briffa *et al.,* 2020). However, this condition is dangerous for the biota that live in the ecosystem because heavy metals in soil and sediment become a source of pollution. Fishing pond sediment is actually battery smelting waste; therefore, the sediment, water, and biota inside are thought to be continuously exposed to hazardous and toxic materials, and over time, the contamination will increase. Hazardous and toxic materials also contaminate plants (Aslam *et al.,* 2021), water (Riani, 2017) and sediment (Fretes *et al.,* 2020), so they will enter the human body (Briffa *et al.,* 2020; Isangedighi and David, 2019) through the food webs (Arnot and Gobas, 2023) and potentially harm the people who consume them (Collin *et al.,* 2022). Used battery processing waste contains various types of heavy metals that are toxic, resistant, and accumulative. Area clean-up has gradually been performed under the Ministry of Environment assignment but not throughout Cinangka Village. In some locations directly converted to fishponds where clean-up has not been carried out, fish and even humans as consumers can be harmed. Unfortunately, the research at Cinangka Village was limited to the restoration of contaminated land from unlicensed used battery smelting activity (Adryansyah *et al.,* 2019), the relationship between blood lead levels and hemoglobin and basophilic stippling in elementary school students (Annashr, 2015), and the study of environmentally friendly lead recycling technology from used batteries (Wiharja, 2004). Meanwhile, research has never been conducted on the impact of heavy metal pollution on the use of fishing ponds where smelting used batteries previously occurred. Therefore, its contamination must be investigated in water, sediment, and living creatures, particularly at the pond sites of the used battery smelting location. Currently, fish farming is the dominant activity in Cinangka Village as a community livelihood that has shifted from used battery smelting activity. Although these locations are generally changed into ornamental fish cultivation ponds, we found a pond intended for fishing. Considering that 12 years ago, the land was a location for used battery smelting, the sediment, water, and fish from the pond are suspected to still be contaminated by heavy metals from the waste. Therefore, this study aims to analyze the hazard and toxic material contamination in water, sediment, and biota that live in the pond, as well as the histomorphology condition of the fish for food safety. This study was conducted in Cinangka Village, Ciampea District, Bogor Regency, Indonesia, in 2023.

MATERIALS AND METHODS

Location and time

This study was conducted in Cinangka Village, Ciampea District, Bogor Regency, Indonesia. Cinangka Village, a former area for used battery smelting, was closed 12 years ago by the government of the Republic of Indonesia. Some of the waste originating from the smelter has been encapsulated. Sampling locations were determined based on purposive sampling. A map of the locations of the sampling stations is presented in Fig. 1.

Tools and materials

The materials are samples of water, sediment, aquatic plants (root, stem, and leaf), fish, and chemicals for heavy metal and histomorphology analyses. The tools used in this study are a global

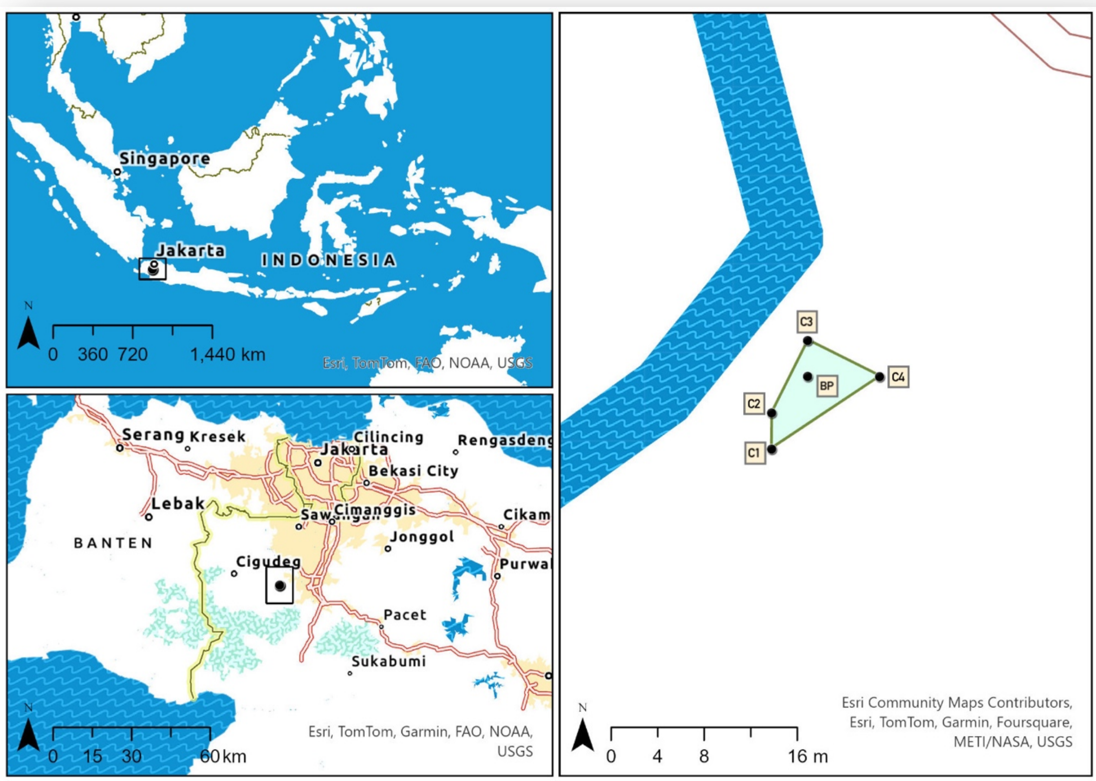

Fig. 1: Geographic location of the study area in Cinangka Village, Ciampea District, Bogor Regency, Indonesia

positioning system (GPS), inductively coupled plasma-optical emission spectrometry (ICP-OES) Agilent 5110, an oven, a blender, supporting laboratory equipment, glassware, a microtome, and a sample container. Primary data were obtained using trace metal analysis of water, sediment, plant, and fish samples. In addition, analysis of histomorphology was performed for the flesh, gills, liver, spleen, kidney, and gonad/ovary of goldfish (*Cyprinus carpio*). The goldfish used were three fish weighing 100–130 g each.

Determination of the sampling locations

Sampling was determined by purposive sampling (only one pond was used as a fishing pond). Covering approximately 150 m^2, the fishing pond is owned by the locals and intended for refreshing fishing activity. Water and sediment samples were taken at five sampling points, four at the corners (C1, C2, C3, C4) and one at the burning point (BP) in the middle of the pond with three replications for each. Aquatic plant samples were collected from the most dominant types in the pond. Water and sediment samples were analyzed in the laboratory using the Standard National Indonesia (SNI) and American Public Health Association (APHA) standard methods.

Heavy metal analysis of Pb, Zn, As, and Fe

Heavy metal analysis in water, sediment, aquatic plants, and fish was conducted using ICP-OES. OES-ICP is a type of ICP that uses plasma as a source of atomization and excitation. The samples of fish organs, aquatic plants, and sediment were dried at 50°C and set aside until completely dry. A total of ± 0.05 g of each sample with a determined water content was placed in a melting tube, then added with concentrated nitric acid (HNO_3) and hydrogen peroxide (H_2O_2) at a ratio of 6:4. This solution was rested for 4 h and then heated for 4 h at 110°C. The solution was then cooled and filtered with 0.42 µm Whatman filter paper, transferred to a volumetric flask, and diluted by adding distilled water to 25 mL. Next, a centrifuge was used to separate the sludge from the filtrate. The filtrate was analyzed using ICP-OES according to the equipment's operational procedures. To perform heavy metal analysis on the water, a 10 mL water sample was put into a digestion flask, and then 0.2 mL of HNO_3 (1 + 1) and 0.1 mL of hydrogen chloride (HCl) (1 + 1) were added to this flask. Then, perform the heavy metal digester for 15 min at 95°C. Next, the sample was left to cool. The cooled sample was filtered using Whatman filter paper No. 41, and the volume was adjusted to 10 mL. Furthermore, the heavy metal content in samples of water, sediment, aquatic plants, and their respective organs was measured using ICP-OES at optimum conditions. To analyze heavy metals, standard solutions were prepared using a multilevel dilution technique from the chloride or nitrate salt and then dissolved with 100 mL of distilled water so that the concentration became 500 parts per million (ppm). The standard solution concentrations used were 0.01, 0.05, 0.10, 0.50, 1.00, 2.50, and 5.00 mg/L. The wavelength (λ) used for Pb, Zn, As, and Fe was 283.30, 334.5, 193.7, and 248.3 nm, respectively.

Maximum tolerable index

The limit of consumption in one week or the maximum tolerated index (MTI) can be determined by calculating the maximum consumption per week or the maximum weekly intake (MWI), using Eq. 1 (Turkmen *et al.,* 2009).

$$\mathrm{MWI}\left(\mathrm{mg/kg}\right) = \text{body weight}^{(a)} \times \mathrm{PTWI}^{(b)} \qquad (1)$$

where MWI = maximum weekly intake: milligram per kilogram (mg/kg)

a) Average adult weight of 60 kg; child weight of 15 kg

b) Provisional tolerable weekly intake (PTWI) is the maximum tolerance limit per week issued by the food agency in units of µg/kg body weight

PTWI is issued by the Joint FAO/WHO Expert Committee on Food Additives (JECFA), an international reference and recommendation of food safety (Turkmen *et al.,* 2009). An MTI calculation assumes that a person with a certain body weight will consume some heavy metals in flesh with the same content for a week. The MTI value is determined using Eq. 2 (Turkmen *et al.,* 2008).

$$\mathrm{MTI} = \frac{\mathrm{MWI}}{\mathrm{Ct}} \qquad (2)$$

where MTI = maximum tolerable intake (kg/week)

MWI = maximum weekly intake (maximum consumption per week (mg))

Ct = concentration of certain specific heavy metals found in fish flesh (mg/kg)

Bioconcentration factor (BCF)

The bioconcentration factor was measured to determine the ability of each heavy metal to accumulate in parts of aquatic plants. The calculation is performed by dividing the concentration of the trace element in parts of the plant by the initial concentration of this element in the water as its environment. The BCF is calculated using Eq. 3 (Wang, 2016).

$$BCF= C_{plants}/C_{media\ ambient} \quad (3)$$

where C_{plants} = heavy metal concentration in parts of aquatic plants (ppm)

$C_{media\ ambient}$ = heavy metal concentration in water (ppm).

Histomorphology analysis

Fish tissue was prepared for histomorphology analysis by dissecting the gills, liver, spleen, and flesh, then cutting these organs into approximately 1 × 1 cm squares. The organs were preserved in formalin 10 percent (%) with a ratio of 1:10 for 1 d. Precipitating fixatives were applied by soaking each specimen gradually in 70%, 80%, 90%, and 100% alcohol solution for 2 h, then in xylene for 4 h. The specimen was then embedded in liquid paraffin in a hot tissue embedding center (hot plate of 65°C) and then cooled in a freezer for 5–10 min. Using a microtome, the organ was then cut into a thickness of 4–5 µm, stained with haematoxylin/eosin (HE), and observed using microphotography.

RESULTS AND DISCUSSION

Condition of Cinangka village

Cinangka Village is located in Ciampea District, Bogor Regency, at an altitude of approximately 350 m. Since 1978, Cinangka Village has been a location for illegal battery smelting. The work is performed by a home-scale industry using the traditional method. The process begins by splitting a battery using an ax or a large knife. Some sulfuric acid (H_2SO_4) liquid is collected for later use, and some is commonly disposed of at once in the environment. The purpose of this used battery smelting/recycling process is to collect the lead ingots, which then become raw materials for batteries, electronics, paint, glass, etc. This industry generates waste of lead and its associated minerals. Meanwhile, other parts such as a sulfuric acid liquidaren are sold to the bottle washing industry, the emptied plastic boxes are sold for recycling into plastic pellets, and nonlead battery cells that have been extracted from the fiber are recycled into lead. Separating or removing lead from the battery cells leaves behind the fibers. Before disposal, these fibers are washed with water to recover any remaining lead. However, the fibers still contain lead, which is a concern. Another concern is that the fibers that are disposed of in the ground or used as a mixture for landfill still contain lead and other metals that can pollute the surrounding environment. In addition, fibers are thought to contain asbestos, which can cause itching if it comes into direct contact with the skin. Another danger is that asbestos can be inhaled; according to Vimercati *et al.* (2019) and van Zandwijk *et al.* (2020), asbestos can cause respiratory diseases and cancer in humans. H_2SO_4 in battery fluid that is carelessly disposed of will not only kill soil-borne microbes but also raise concerns about seepage into the soil, thus potentially polluting water sources. H_2SO_4 is very corrosive to all biological tissue (Enghoff, 2021). The used battery smelting process uses a traditional stove with firewood. The burning process is performed in an open area, with smoke rising everywhere and dispersing by the natural dynamics of wind. However, this smoke contains heavy metal particles, including lead, Pb, and associated minerals, which can be inhaled by workers and other people. Through the burning process, the potential for air pollution is quite high. Air pollution will fall to the earth through gravity-induced dry deposition, and pollutants in the atmosphere will also fall to the earth in rainwater through wet deposition (rain), polluting water and soil. Furthermore, runoff will carry these metals into the aquatic ecosystem. Smelting used batteries also generates solid waste in the form of slag. Slag is a mixture of carbon and tin impurity metals such as Fe and other metals, generally in the form of irregular lumps. Used battery smelting generates a large amount of slag. Because the burned material is metal with lead as the main component, the waste contains many dangerous and toxic materials that have the potential to contaminate and pollute soil, water, and the environment, as has happened in Nigeria (Afolayan, 2018; Oloruntoba *et al.,* 2021). Metals are very resistant and have a long half-life (Raj and Das, 2023), so the potential for postclosure pollution in battery smelting activities in Cinangka Village is also high.

Heavy metals in the fishing pond

Heavy metals in water

Because the fishing pond was once a location used for battery smelting activity, it was built among leftover solid slag waste. Slag is a mixture of lead metal, carbon, and lead impurity metals. The results of the study we conducted between 2012 and 2023 show that metal impurities in lead waste include Zn, As, Cu, Mn, titanium (Ti), Sr, tin (Sn), and Cd. The research conducted in Nigeria by Oloruntoba *et al.* (2021) obtained similar results, and a study by Afolayan (2018) uncovered the Fe pollution of battery waste. Because only Pb and Fe were continuously present at relatively high concentrations, we analyzed these elements, along with two metals that were continuously present at relatively low concentrations, i.e., Zn and As. Therefore, the sediment and water and their biota are also often contaminated by these metal pollutants. The results show that water, sediment, and biota were still contaminated by lead and other metal impurities 12 years after gradual closure commenced, as seen in Tables 1, 2, 3, and 4. A high level of heavy metals is dissolved in the water because used batteries were burned at the fishing pond. Heavy metals are naturally persistent and do not degrade through microbial activity (Zhang *et al.*, 2015); therefore, they remain in the pond sediment. According to Huang *et al.* (2020), heavy metals in sediment become a source of pollution for water and remain as such as long as no remediation action is taken.

The center of the pond, where used battery burning took place, has higher concentrations of Pb, Zn, As, and Fe than other sampling points. Sampling point C1 has the lowest concentration of heavy metals. The center of the pond is thought to still contain a large amount of battery-burning waste and is suspected to be the point source of pollution because heavy metals spread from the point source to other places (Briffa *et al.*, 2020). Far from the center, the concentration decreases with increasing distance (Zhou *et al.*, 2020). The difference in concentration between the sampling points indicates that the pool did not have perfect mixing (homogeneity). This attribute is observed because the pond construction only has a tiny inlet with low water flow (and relatively no outlet), so it cannot achieve homogeneous water quality. Table 1 also shows that all of the heavy metals were above the water quality standard (Government Regulation, 2021). (For Fe, Class 1 water quality standards are used because Class 2 standards do not exist.) This condition means that the fishing pond is polluted by heavy metals such as Pb, Zn, As, and Fe. The average concentrations are 2.2, 7.31, 0.98, and 2.18 ppm for Pb, Zn, As, and Fe, respectively. The concentration of dissolved Pb in water is low because this heavy metal is very insoluble (Santucci and Scully, 2020). The pH at the study location, which is neutral, tends to be alkaline, so it does not promote lead solubility (Saalidong, 2022). Because the Pb concentration is lower in the water than in the sediment, it is thought that water pollution in the pond will persist over a long period until the Pb from the sediment is depleted.

Heavy metals in the sediment

The sediment analysis results in Table 2 show that the highest Pb concentration of 12875.23 ppm is found at the BP location. The Pb concentration is very high, even far above the quality standard concentration for the total concentration of group A (TK-A), namely, 6,000 ppm (Appendix V of number 101 of 2014 concerning the management of nonhazardous and toxic wastes; Government Regulation, 2014). The sediment in the range of 2037.74–4199.11 ppm in the non-BP location is also categorized as soil dominated by hazardous and toxic materials,

Table 1: Heavy metals in water

Metals	Unit	Sampling point					Average	Standard
		C1	C2	BP	C3	C4		
Pb	ppm	0.98	1.54	4.08	3.14	1.26	2.2	0.03*
Zn	ppm	5.06	6.59	10.28	8.4	6.22	7.31	0.05*
As	ppm	0.62	0.76	1.56	1.28	0.68	0.98	0.05*
Fe	ppm	1.48	2.02	2.98	2.68	1.74	2.16	0.30**

*) Government Regulation, (2021): Environmental Protection and Management, No. 2 (Appendix VI Water Quality Standards Class 2)

**) Government Regulation, (2021): Environmental Protection and Management, No. 2 (Appendix VI Water Quality Standards Class 1)

Table 2: Heavy metals in the sediment

Metals	Unit	Sampling point					Standard
		C1	C2	BP	C3	C4	
Pb	ppm	3092.27	4199.11	12875.23	6396.94	2037.74	57*
Zn	ppm	84.68	95.91	139.84	107.15	83.18	200*
As	ppm	68.32	143.12	379.16	203.92	89.75	11*
Fe	ppm	45544.3	49151.27	43285.43	45988.97	50283.51	(%)2**

*) $SedQC_{SCS}$ (sediment quality criteria) for sensitive contaminated sites in British Columbia

**) Lowest effect level on Guidelines for the Protection and Management of aquatic sediment quality in Ontario.

referring to Government Regulation Number 101 of 2014 (Government Regulation, 2014), such that it can severely impact and threaten the health of organisms as well as the ecosystem itself. According to these results, the use of former BP locations and waste storage sites as fishing ponds is not feasible, particularly for cultivating edible fish. Both categories of contaminated soil and dominated contaminated soil act as a pollution source until all of the hazardous and toxic waste is leached. This finding agrees with the research of Chiaia-Hernandez *et al.* (2022), who stated that sediment can be a sink or a point source of pollutants. Therefore, even after 12 years, the study location still belongs to the category of hazardous and toxic waste sites. Consequently, without clean-up or remediation action, water pollution in the pond will continue to contaminate the biota. Consuming this biota would be very dangerous and possibly even result in genetic damage (Da Costa Araújo *et al.*, 2023).

Table 2 also shows that at all sampling points, the concentration of Pb, as well as As and Fe, far exceeds the sediment quality standards of $SedQC_{scs}$ of British Columbia. Only the Zn concentration was below the quality standard at all sampling points. These results show that the sediment in this fishing pond is generally polluted by heavy metals such as Pb, As, and Fe. This finding strengthens the suspicion that the pollution source is the location where used batteries were burned. Moreover, it proves that sediment, which is dominated by used battery waste that is more than 12 years old, is still an effective source of heavy metal pollution to contaminate the water and sediment. This finding agrees with the results of Sulistyowati *et al.* (2023) that sediment contaminated with heavy metals becomes a point source of pollution. Therefore, although pollutant-generating activities have ceased, pollution will continue to afflict aquatic ecosystems, the source of which being sediments containing heavy metals. Table 2 shows that the heavy metal concentration at the BP location is the highest, particularly for Pb. Similar to heavy metals in water, heavy metals in sediment can spread into surrounding areas (Briffa *et al.*, 2020), decreasing in concentration with distance (Zhou *et al.*, 2020). The other dominant heavy metals in this study were Zn, As, and Fe. Zn and Fe are essential microelements, but according to Yousif *et al.* (2021), the negative impact of high levels of essential elements can be equivalent to or even worse than that of nonessential metals. For example, excess Zn is toxic to the body of biota (Hussain *et al.*, 2022). Excessive Fe is also a toxin in the body (Ghosh, 2020). Arsenic is a nonessential heavy metal that has long been known to be toxic and harmful to living organisms (Dai *et al.*, 2023), affecting biodiversity and ecosystem stability (Pimentel, 2005). Excessive Fe in the environment pollutes the soil and disrupts the ecosystem, including plants (Li *et al.*, 2015). Likewise, the negative impact of excess Zn will disrupt microbial diversity and soil hydrogen potential (Gautam *et al.*, 2016).

Heavy metals in goldfish (Cyprinus carpio)

Tables 1 and 2 show that in addition to Pb, metals such as Zn, As, and Fe are consistently found in high amounts in used battery waste as bottom ash, as is the case at a battery recycling center in Nigeria (Oloruntoba *et al.*, 2021). Therefore, the study results in Table 3 show that heavy metals were also detected in the organs of goldfish, with Zn present in the highest concentration. Although Zn is a mineral needed by the body, it can be dangerous in large amounts (Liang *et al.*, 2022). Excess Zn intake has toxic effects such as gastrointestinal symptoms (Plum *et al.*, 2010), particularly those related to modulating gastrointestinal flora (Piavchenko *et al.*, 2020). Excess Zn also inhibits the absorption of copper and iron that the body needs (Arredondo *et al.*, 2006), resulting in

Table 3: Heavy metals in goldfish

Metals	Unit	Liver	Kidney	Gills	Flesh	Ovary	Spleen
Pb	ppm	2.42	1.98	1.12	0.21	3.46	1.86
Zn	ppm	178.62	184.28	162.46	128.03	198.06	144.8
As	ppm	1.40	1.26	1.04	0.24	1.48	1.09
Fe	ppm	21.26	22.21	26.04	8.71	26.76	20.71

Table 4: Heavy metals in aquatic plants (water hyacinths)

Metals	Unit	Root	Stem	Leaf
Pb	Ppm	2362.48	162.55	381.85
Zn	Ppm	212.66	34.02	69.05
As	Ppm	386.99	28.55	70.14
Fe	Ppm	35970.04	2948.91	5295.15

copper deficiency (Maywald *et al.,* 2017), interferes with the activity of amylase and lipase enzymes (Foote *et al.,* 2020), and can be toxic to cells by disrupting biological functions (Hussain *et al.,* 2022).

Table 3 shows that the liver has higher Pb, Zn, As, and Fe contents than other organs. The liver plays an important role in contaminant storage, redistribution, and detoxification (Evans *et al.,* 1993). The liver also tends to accumulate high amounts of heavy metals because of its role in metabolism (Ben Salem *et al.,* 2014) and contains more metallothionein than other tissues, which functions in the absorption, storage, and excretion of metals, as do the gills and kidneys (Girgis *et al.,* 2019). The high presence of metallothionein in the liver has been linked to its function in binding metals and protecting against the toxic effects of certain metals (Mason and Jenkins, 1995; Torres *et al.,* 2016). After the liver, the kidneys also accumulate high levels of heavy metals compared with other organs. This accumulation results from their role as an excretory system in fish, which filters blood so that useless and toxic objects are excreted from the body (Kumar *et al.,* 2024). Considering their limited function, the kidneys can accumulate a large amount of heavy metals. Heavy metal accumulation also appears in goldfish gills. In addition to metabolism (Tashi *et al.,* 2022), respiration, excretion, and osmoregulation are also functions of gills in fish. The heavy metal content in water can generally be described through the gills (Aytekin *et al.,* 2019). Gills have a higher tendency to accumulate heavy metals (Karar *et al.,* 2019). According to Olgunoglu *et al.* (2015), this accumulation occurs because the gills are constantly in direct contact with water. In addition, the epithelium in the gills is very thin compared with other organs (Shah *et al.,* 2020), so heavy metals dissolved in water can be easily absorbed by the gills. Yimaz (2005) stated that flesh does not actively accumulate heavy metals. According to the results of this study, the heavy metal content is lower in fish than in other organisms. However, fish flesh is commonly consumed, so even at low contamination levels, it can harm health. Heavy metal content is higher in the ovaries than in other organs. This higher content is observed because the ovaries are rich in proteins, some of which have sulfhydryl groups, so heavy metals are relatively easily bound. According to Naz *et al.* (2023), metallic trace elements have devastating effects on several functions, including the reproductive system. In plants, heavy metals have various effects, such as inhibiting plant growth, causing cell damage (Meng *et al.,* 2023), changing soil structure, and disrupting microorganisms (Kaur and Gard, 2021). Therefore, excess Zn also threatens to disrupt all life forms, including animals, plants, and soil microorganisms, and even humans. In addition to Zn, Fe is also needed by all living things. However, the presence of iron that exceeds a limit will cause various problems, such as increasing oxidative stress (Maher, 2018). Iron overload due to oral intake is categorized as a secondary classification, but it can also cause ineffective erythropoiesis, resulting in thalassemia, sideroblastic anemia, and myelodysplastic syndromes (Kohgo *et al.,* 2008). Iron deposition can damage organ function and promote cell death, fibrosis, and carcinogenesis (Pietrangelo, 2004). Therefore, the extremely high iron concentration in bottom ash waste from the traditional used battery smelting process will increasingly contribute to complexity problems in an ecosystem and its biota. Another mineral that is consistently present in bottom ash is arsenic (As), which also harms living creatures and the environment. Arsenic is also naturally accumulative; its exposure affects the neural system and even disrupts coordination (Tyler and Alan, 2014), interferes with metabolic pathways (Witkowska *et al.,* 2021), inhibits energy production in cells (Zhao *et al.,* 2013), and damages DNA repair (Andrew *et al.,* 2006). Long-term exposure to arsenic causes cancers of the lung, skin, and bladder, developmental defects, diabetes, and pulmonary and cardiovascular diseases (Farzan *et al.*, 2013). These minerals can inhibit each other. For example, the presence of Zn in the soil inhibits Pb absorption (Thanh *et al.,* 2021), and Zn also reduces the negative impacts of Pb and As, as they compete for binding to enzymes and proteins, reducing the toxicity of heavy metals. However, Pb combined with As increases toxicity (Kiper, 2023). This increase results in bottom ash waste from used battery smelting with of various types of heavy metals being very dangerous. Various types of heavy metals in waste from the process increase the cumulative risk and result in bioaccumulation.

Heavy metals in aquatic plants

Aquatic plant species of water hyacinth (*Eichornia crassipes*) were discovered during a field survey. The water hyacinth was not planted intentionally but may have been dragged in following the flow of water from the inlet. From visual observation, the stems do not grow well and look stunted but densely dominated compared with other plants. Other types of aquatic plants are few and have relatively dry leaves on their sides. Because water hyacinth is abundant, it is deemed necessary to investigate the heavy metal contamination in water hyacinth and find the potential of this plant for use as a bioremediation agent in ponds built on previously used battery smelting or waste disposal sites such as the study location. Because not all plants can live under conditions of high heavy metal contamination, we feel this investigation is necessary because the traditional method of used battery recycling in Indonesia is not only practiced in Cinangka. Waste in the form of bottom ash residue accumulates in nature such that heavy metals in the water enter and accumulate in the roots, stems, and leaves of water hyacinth plants (Table 4). Water hyacinth has a high concentration of metals because it can absorb heavy metals (Ndimele and Jimoh, 2011). Table 4 shows that Pb, Zn, As, and Fe accumulation is higher in the roots than in the stem and leaf. This disparity is observed because the roots filter pollutants and accumulate them first. These roots can capture and absorb heavy metals dissolved and dispersed in water (Enyoh *et al.,* 2013). Similar to fish, plants need heavy metals, including Zn and Fe, but both of these elements can become toxic if their concentration exceeds a specified limit (Alengebawy *et al.,* 2021), as happens to water hyacinth (*Eichornia crassipes*) in ponds.

Heavy metals in water can enter and accumulate in the tissues of water hyacinth plants, which is known as the bioconcentration factor (BCF). The accumulation of Pb was higher in the root than in the stem and leaf. The accumulation of Zn in the root, stem, and leaf was quite low but higher in the root than in the stem and leaf. The highest accumulation of As and Fe was also in the root (Table 5). Table 5 shows that the BCF of water hyacinth for Zn is categorized as low accumulation in all parts of the plant. In contrast, Fe shows high accumulation in all plant parts. Roots have the highest bioaccumulation ability from water. Pb accumulation in the root is categorized as high (BCF > 1000). The roots have high accumulation because they naturally filter heavy metal particles and have a high capacity to absorb heavy metals dissolved in water (Skinner *et al.,* 2007). In addition, these results indicate that water hyacinth is an aquatic plant that can live in aquatic ecosystems with a high concentration of Pb as well as other metals. Thereby, it can be considered a phytoremediator in ponds or polluted wetlands contaminated with Pb, Fe, As, and Zn.

Heavy metals also accumulated in the stems and leaves of water hyacinths (Table 5), which agrees with the finding that heavy metals accumulate in the stem through the plant's vascular system, such as xylem (Sulaiman and Hamzah, 2018). In particular, some heavy metals enter leaf tissue through transpiration and diffusion from soil and water (Street, 2012). Accumulation of heavy metals in leaves can also occur through absorption by the stomata on the leaf surface (Shahid *et al.,* 2017). As in animals, the accumulation of high amounts of heavy metals in water hyacinth causes oxidative stress (Malar *et al.*, 2014), resulting in nutrient deficiencies and damage

Table 5: Bioconcentration factors in aquatic plants (water hyacinths)

Metals	Root	Stem	Leaf
Pb	1073.85	73.89	173.57
Zn	29.09	4.65	9.45
As	394.89	29.13	71.57
Fe	16500.02	1352.71	2428.97

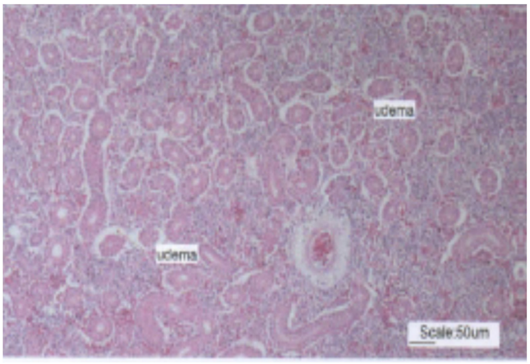

Fig. 2a: Edema in the kidney tissue (scale 50 µm)

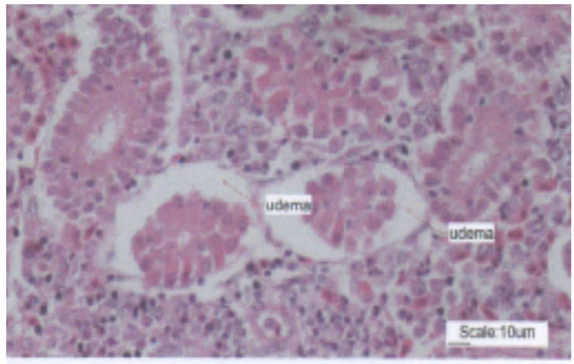

Fig. 2b: Edema in the kidney tissue (scale 10 µm)

Fig. 3a: Edema and hyperplasia in the gills (scale 50 µm)

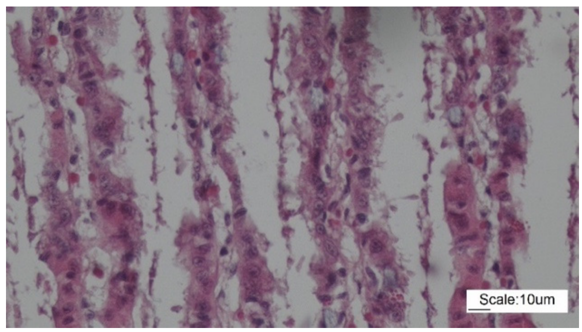

Fig. 3b: Lysis in the gills (scale 10 µm)

to cell membranes and organelles, and affects different metabolic pathways, resulting in their ceased growth and development (Chaitanya *et al.*, 2023). After death, the water hyacinth is not removed from the aquatic ecosystem, becoming a point source of pollution in this ecosystem.

Histomorphology of the goldfish organs

In this study, a histomorphology analysis was also conducted on goldfish that lived in a fishing pond to observe the effect of heavy metals on the fish organs. Histomorphology results showed that goldfish organs suffer several abnormalities in the kidney, gills, spleen, liver, and ovary. If it is closely detailed from the histological shape, damage is not due to the presence of disease agents and parasites but is caused by the presence of toxic substances. Histomorphology analysis showed that the kidneys (Fig. 2) and gills (Fig. 3) of fish experienced edema, whereas melano-macrophage centers (MMCs) were found in the spleen (Fig. 4) and liver (Fig. 5b), which also showed fatty degeneration (Fig. 5a). Lysis in the gills and ovary is seen in Figs. 3b and 6, respectively. Epithelial hyperplasia is visible on the gills (Fig. 3a), whereas normal flesh tissue is shown in Fig. 7. Edema associated with kidney damage is due to fluid infiltration into tissues. Necrosis or cell death in the epithelium can occur if the condition

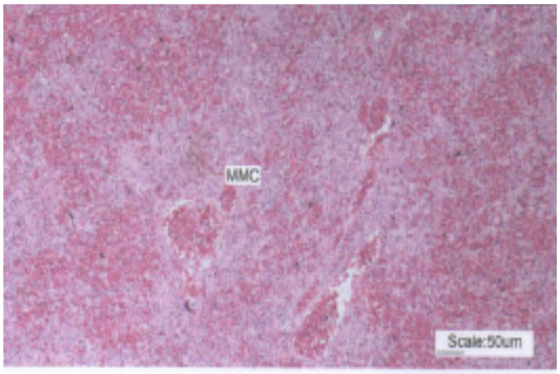

Fig. 4a: MMC in the spleen tissue (scale 50 µm)

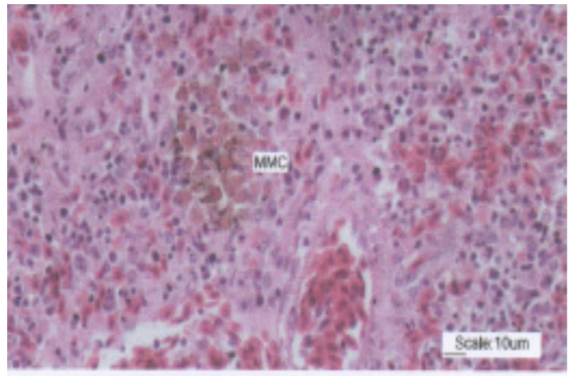

Fig. 4b: MMC in the spleen tissue (scale 10 µm)

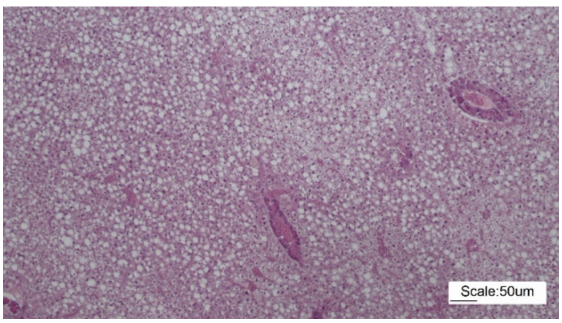

Fig. 5a: Fatty degeneration in the liver tissue (scale 50 µm)

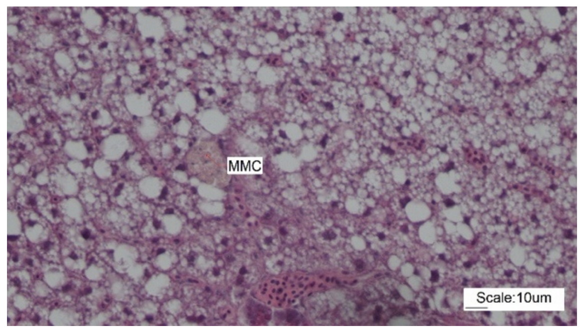

Fig. 5b: MMC in the liver tissue (scale 10 µm)

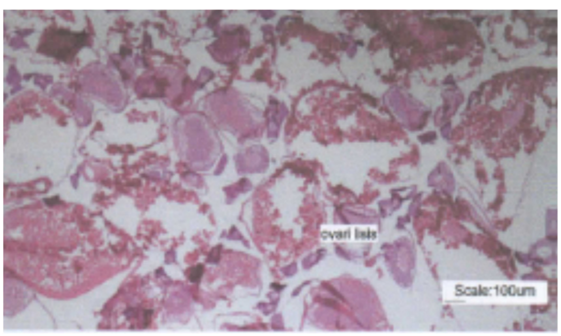

Fig. 6: Lysis in the ovary tissue (scale 50 µm)

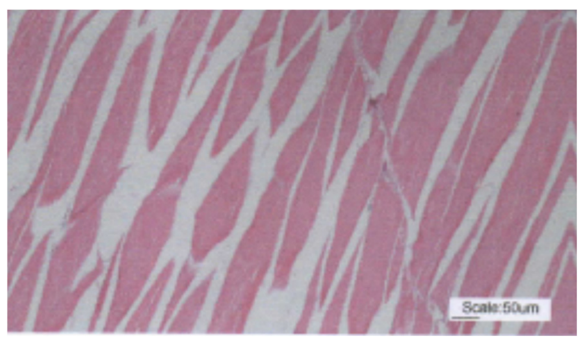

Fig. 7: Normal flesh tissue (scale 50 µm)

of edema continues (Khalid and Azimpouran, 2023). Table 3 shows that goldfish organs have a high Zn concentration. Therefore, Zn is thought to cause damage to these organs and necrosis. This finding agrees with the opinion of Hussain *et al.* (2022) that Zn often disrupts important biological functions triggered by the inhibition of protein thiols through metalation errors with other metals. Zn can also destroy cell membranes and then accumulate in the cytoplasm, causing cell death (necrosis). Pb (Metrycja *et al.,* 2020) and As (Del Giudice *et al.,* 2013) can also cause necrosis. In fact, according to Mancardi *et al.,* (2021) excess Fe in the body will also cause abnormalities, which can lead to necrosis. Another histopathologic change caused by metal toxicity is hyperplasia found in the gills (Baptista *et al.,* 2023). MMCs increase in size or frequency with environmental stress and have been suggested as reliable biomarkers for water quality in terms of deoxygenation and iatrogenic chemical pollution (Agius and Roberts, 2003). The lesion in the ovary can be caused by lead nitrate after eight weeks of exposure, and the abnormalities include mild to severe degeneration and necrosis of ovarian follicles (Adeyemo, 2008). The results of this histomorphological analysis show that the liver tends to experience more damage, which is due to the accumulation of higher levels of heavy metals; therefore, the liver tends to be the organ that is more frequently damaged in fish (Shahjahan *et al.,* 2022).

Food safety of fish flesh from the fishing pond

Although fishing is for refreshing activities, goldfish in the fishing pond are intended for consumption, as these species are generally consumed. In fact, exposure to metals will harm humans. Pb exposure can cause health problems such as hypertension, kidney failure, heart disease, neurological disorders, reduced fertility, cancer, and even death (Isangedighi and David, 2019). Therefore, the food safety of goldfish from this fishpond is important to study. The results show that heavy metals such as Pb, Zn, As, and Fe accumulated in various fish organs (Table 2). However, among these organs, only the flesh is consumed; therefore, food safety analysis is only applied to the flesh. For more details, the PTWI issued by JECFA for each heavy metal is shown in Table 6.

Calculation of MWI results for fish flesh is performed using adult body weight. The average body weight of an adult is assumed to be 60 kg. For children, a weight is 15 kg is assumed. This value is then multiplied by the PTWI of each heavy metal to obtain the MWI value. MWI is the maximum amount of each heavy metal that is allowed to enter the body via consumption. The results are shown in Table 7.

Consumption of fish contaminated with heavy metals needs to be limited, severely restricted, or prohibited, in accordance with the opinion of Yousif *et al.* (2021), who stated that fish are generally the main source of exposure to heavy metals in humans. In addition, the consumption of contaminated fish over a long period can harm human health. This observation agrees with Strydom *et al.* (2007), who mentioned that the consumption of fish contaminated with heavy metals must be limited because heavy metals can disrupt cell organs down to the molecular level, thereby harming human health. These conditions can even impact the processes of glycolysis, the Krebs cycle, and lipid metabolism in organism cells. The calculations in Table 7 show that among the heavy metals, the lowest amount of permitted consumption is for Zn. In this case, according to the Zn concentration in the fish flesh, the amount of goldfish flesh that can be consumed in one week is only 0.003 kg or 3 g for an adult with a body weight of 60 kg and only 0.0008 kg or 0.8 g for a child with a body weight of 15 kg. Thus, children are only allowed to consume in very small amounts, even identical to not being allowed to consume goldfish flesh originating from the fishing pond in Cinangka Village. This is because children are more susceptible to the negative impacts of exposure to heavy metals (Alosman *et al.,* 2019), because vital organs such as the neural system (central/brain and peripheral) and the liver are in their development period; thus, heavy metal exposure can lead to abnormal development. Children also have a higher metabolism, so heavy

Table 6: PTWI for each metal

Metals	PTWI (μg/kg body weight) per week
Pb	25
Zn	7
As	15
Fe	5.6

Table 7: MWI and MTI goldfish flesh for adults and children

Metals	Adult		Child	
	MWI (mg)	MTI (kg/week)	MWI (mg)	MTI (kg/week)
Pb	1.5	7.14	0.375	1.79
Zn	0.42	0.003	0.105	0.0008
As	0.9	3.75	0.225	0.94
Fe	0.336	0.04	0.084	0.010

metals in contaminated food are absorbed more efficiently by their bodies. Moreover, because children have a lower body weight than adults, in the same amount of food, the concentration of heavy metals will be higher, thus making it more harmful. Children, pregnant women, and breastfeeding women are not recommended to consume goldfish from fishing ponds in Cinangka Village. This study also showed that used battery waste in Cinangka Village contained not only Pb but also other heavy metals. In this study, Zn was actually more dangerous. Zn is an essential mineral needed by the body. The recommended daily intake of Zn is 15 mg for adults (Agnew and Slesinger, 2022) and 5 mg for children 4–8 years old (Singh and Taneja, 2009). Oral Zn intake is mainly absorbed in the jejunum (intestine). Plasma zinc is mostly bound to albumin, and a small portion is found free in plasma. The body's response to excess zinc is to produce more metallothionein to reduce the concentration of free zinc (Ruttkay *et al.*, 2013). Zn is antagonistic to copper (Cu), which has the highest affinity for metallothionein, which decreases Cu levels that are needed by the body (Marastoni *et.al,* 2019). Homeostasis, to a certain limit, is controlled by excretion of metallothionein–zinc complexes via bile and feces. However, this mechanism is too slow after a large overdose; therefore, the presence of high Zn results in Cu deficiency. In a review of food safety, although smelting ceased 12 years ago, sediment is still categorized as hazardous and toxic waste. Moreover, not only Pb but also other heavy metals can be a danger to fish and the humans who consume them. Therefore, the consumption of fish from this area by adults must be strictly limited, whereas children, pregnant women, and breastfeeding women should not be allowed to consume goldfish and other food fish from this area. Global annual lead use for batteries is very high (9,024,000 tons), 85.18% of the total demand (Majumder *et al.,* 2021), resulting in a large amount of used battery waste. Despite being submersed in water for more than 12 years, the heavy metals are still high in concentration and have merged with the soil. This high concentration is observed because lead persists in the environment and cannot be degraded by microbes; it even accumulates in soil, water bodies, and sediments through the deposition process (Zhang *et al.,* 2015). This result agrees with research by Collin *et al.* (2022), who stated that lead binds very strongly to soil particles and is found in the top layer of soil. When used batteries are burned, lead and other metals, by wet deposition (rain) or dry deposition, falls to the ground. From the ground, it enters water bodies through runoff during rain and is thus transferred to animals and plants. This condition is very risky, particularly for children. According to Engwa *et al.* (2019), in children, lead accumulates in the digestive tract and central nervous system, which can be acute or chronic with more severe effects. This severity is observed because compared to adults, children absorb 4–5 times more lead, whose main target is the nerves (Ungureanu and Mustatea, 2022). Therefore, children are not allowed to consume goldfish from this area. In addition, the monitoring of lead exposure must be performed carefully because the impact of lead accumulation in the body is generally not immediately visible but will appear years later. Therefore, traditional used battery smelting is a serious challenge for the world (Charkiewicz and Backstrand, 2020).

CONCLUSION

The water and sediment of a fishing pond that previously had been used as a location for used battery smelting were polluted by heavy metals even after 12 years. According to the classification of the total Pb concentration found in pond sediment, sediment in Cinangka still belongs to the category of hazardous and toxic waste, so the sediment has potential as a point source of heavy metal pollution for the pond ecosystem that is always there and can continue to be a source of pollution. The results show that the heavy metal concentration in sediments is higher than the SedQCscs of British Columbia quality standards for Pb and As, particularly at the burning point, which has the highest concentration among the sampling points in the pond. Meanwhile, the Zn concentration is still below the quality standard. Water hyacinth plants that live in ponds accumulate heavy metals from water and are contaminated by heavy metals such as Pb, Zn, As, and Fe. Water hyacinth can be considered a phytoremediation agent for aquatic ecosystems polluted by high levels of heavy metals. Because of the high Fe concentration in water, Fe is the highest accumulated metal in all parts of the water hyacinth, categorized as high accumulation from the BCF analysis. The bioaccumulation of heavy metals in water hyacinth is very high, with the highest concentration in the roots, followed by leaves, and the smallest in the stems. The liver, spleen, gills, and flesh of goldfish are also contaminated by heavy metals Pb, Zn, As, and Fe. Among these metals, Zn in particular is detected in goldfish flesh at concentrations that make goldfish unsafe for consumption. As the results obtained from this research indicate, sediment is the ever-present point source of pollution, and the water, which is the habitat for goldfish, will also be contaminated by these heavy metals. Through the bioaccumulation process, these metals will be detected in the organs of fish that live in the pond. In addition, it is not surprising that heavy metals have damaging effects on fish. Therefore, the results also showed that the goldfish suffered damage to their organs, namely, edema in the kidneys and MMCs in the spleen, and lysed ovary cells. Because of contamination in the flesh, consumption by adults should be limited to only 3 grams/week (g/wwek), while consumption by children, pregnant women, and breastfeeding mothers should be prohibited. The land in Cinangka Village should not be converted into a fishing pond. Moreover, if the fishing pond is intended for consumption purposes, then eating fish originating from this area will harm human health because of the amount of heavy metal content that exceeds the maximum permitted limit. The policy regarding closing the resident area in Cinangka will be very difficult to implement. Therefore, the remaining land in this location must be cleaned from the remains of used battery waste. Remediation is a mandatory action to be carried out because it is very dangerous for the people living in the village, particularly children. Areas that have not been cleaned up should not be inhabited. The diseases or any health disorders of the people living there could be interesting for further research to see as an initial hypothesis whether long-term exposure to heavy metals is a cause.

AUTHOR CONTRIBUTIONS

E. Riani, the corresponding author, contributed to conceptualization, supervising the study, and writing the manuscript. N.A. Butet performed field sampling and data analysis. M. Anshori participated in data analysis and interpretation. M.R. Cordova prepared the maps and helped in writing the manuscript.

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DISCLAIMER

The fishing pond where the study was carried out is the only one pond used for fishing pond intended for consumption. However, the fishing pond was less profitable for the business. When the article published, the pond was no longer used as a fishing pond, but it was used for cultivating the ornamental fish like other ponds in CInangka Village.

CONFLICT OF INTEREST

The authors declare that there are no conflicts of interest regarding the publication of this manuscript. In addition, the ethical issues, including plagiarism, informed consent, misconduct, data fabrication and/or falsification, double publication and/or submission, and redundancy, have been completely observed by the authors.

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ABBREVIATIONS

%	Percentage
°C	Degree Celsius
μg	Microgram
μg/g	Microgram per gram
μm	Micrometer
λ	Wavelength
APHA	The American Public Health Association
As	Arsenic
BCF	Bioconcentration factor
BP	Burning point
°C	degree Celsius
C_{plants}	Heavy metal concentration detected in part of aquatic plants
$C_{media\ ambient}$	Heavy metal concentration detected in media (water)
Cd	Cadmium
Cr	Chromium
Cu	Copper
FAO/WHO	Food and Agriculture Organization/ World Health Organization
Fe	Iron
g	Gram
GI	Gastrointestinal
GPS	Global Positioning System
H_2O_2	Hydrogen peroxide
H_2SO_4	Sulfuric acid
HE	Haematoxylin/eosin
HCl	Hydrogen chloride
HNO_3	Nitric acid
ICP-OES	Inductively coupled plasma-optical emission spectrometry
JECFA	Joint FAO/WHO Expert Committee on Food Additives
kg	Kilogram
LEL	Lowest effect level
m	Meter
m^2	Square meter
mg/kg	Milligram per kilogram
mg/L	Milligrams per liter
Mn	Manganese
mm	Millimeter
mL	Milliliter
MMC	Melano-macrophage center
MTI	Maximum Tolerance Index
MWI	Maximum weekly intake
Ni	Nickel
nm	Nanometer
pH	potential of hydrogen
Pb	Lead
ppm	Parts per million
PTWI	Provisional tolerable weekly intake
Sb	Antimony
$SedQC_{scs}$	Sediment quality criteria for sensitive contaminated sites
Se	Selenium
Sn	Tin
SNI	Standard National Indonesia
Sr	Strontium
Ti	Titanium
TKA	Total Konsentrasi–A (Total Concentration–A)

UNEP	United Nations Environment Programme
USD	The United States dollar
Zn	Zinc

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