Bioaccumulation of Heavy Metals in Living Organisms, Soil, and Health Risk Assessment: A Systematic Review of Mining Sites in the Philippines

Dianna Jhent S. Cullamar[1]; Levy Donor[2]; Ana Coline R. Cortiñas[3]; Eunice B. Dosmanos[4]
Shamel D. Almendra[5]; Reona Jorelle Manalo[6], and Cristopher B. Parmis[7]
Civil and Allied Department, Chemical Technology Department
Technological University of the Philippines – Taguig Metro Manila 1630 Philippines

Abstract:- Despite the known presence of heavy metals around mining sites, a critical gap exists in understanding how these metals accumulate in living organisms and soil. This lack of knowledge hinders effective management and poses potential health risks to surrounding ecosystems, including humans. This review included articles published between 2014 and 2024 that focused on bioaccumulation of heavy metals in living organisms, soil contamination at mining sites, and health risks associated with mining exposure. Articles were selected based on originality, full-text availability, and English language. Excluded were case studies, reviews without data, or articles lacking full text or English translation. All relevant studies were systematically selected from Google Scholar, ResearchGate, Elsevier, Springer, and Academia.edu to identify relevant research exploring the impacts of mining activities on local biota. The review identified a total of 25 studies. We were able to use 15 of these studies for a more in-depth quantitative analysis. The qualitative analysis of all 10 studies revealed that Arsenic, Copper, Nickel, Mercury, Chromium, Lead, and Zinc are the most frequently observed heavy metals impacting humans near mining sites. Among the identified heavy metals, Mercury and Arsenic stand out as posing the greatest health risk such as skin allergies, respiratory problems and various types of cancer. Their high toxicity and ability to bioaccumulate in the food chain are particularly concerning. Bioaccumulation means these metals become more concentrated at each level of the food web, posing a significant threat to top predators like humans. Specific species demonstrate significant metal accumulation, underscoring the toxicological risks associated with heavy metal bioaccumulation and the need for environmental intervention and monitoring to protect both organisms and ecosystems. Through this systematic review, the researchers aim to shed light on bioaccumulation patterns of heavy metals around mining sites. These findings will be crucial for developing better strategies to mitigate environmental impacts and protect the health of surrounding ecosystems.

Keywords:- *Mining Activities, Health Impacts, Ecological Risk, Phytoremediation, Soil pollution, Human Exposure.*

I. INTRODUCTION

Mining activities, both current and historical, pose significant environmental challenges due to the release of heavy metals into the surrounding ecosystem. This systematic review focuses on the bioaccumulation of heavy metals in living organisms at mining sites and metal contaminants in soil, assessing the consequent health risks. Heavy metals, such as lead, mercury, cadmium, and arsenic, are persistent environmental pollutants that can accumulate in living organisms, leading to toxic effects (Järup, 2003). Understanding the extent and impact of these contaminants is crucial for developing effective mitigation strategies and protecting public health.

The objectives of this review are multifaceted. Firstly, it aims to determine the specific heavy metal contaminants present in the environment surrounding mining sites (Tchounwou et al., 2012). It is also to identify which areas near mining site accumulated the highest concentrations of each heavy metals and pinpoint which organs in living organism are affected by a specific heavy metal. Additionally, it is to understand the recurring health risk of mining sites to humans.

This analysis puts a strong emphasis on assessing the health risks associated with heavy metal exposure. It will evaluate reoccurring health threats to individuals, identifying the impacted body systems and their specific effects and diseases. Furthermore, the study will investigate whether the site's mining status influences its level of hazard.

This study will provide a full understanding of heavy metal bioaccumulation at mining sites and its impact on living organisms by conducting a systematic review of previous research. The findings will aid in the creation of more effective environmental protection policies and health risk management techniques.

II. METHODOLOGY

This study followed a systematic review approach, adhering to the widely recognized PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines. Using PRISMA ensured a rigorous selection process for relevant publications published between 2014 and 2024 that investigated bioaccumulation of heavy metals in living organisms near mining sites.

➢ *Data Sources*

Using the PRISMA guidelines, all relevant published material was carefully selected from a multiple widely recognized search databases, Google Scholar, ResearchGate, Elsevier, Springer, and Academia.edu.

➢ *Literature Search*

To maximize a successful search strategy, the aforementioned databases' search engine used appropriate keywords and Boolean operators such as AND or OR. Three sets of keywords were entered and searched in the online databases. The first set of keywords included terms linked to heavy metal bioaccumulation in living organisms, such as "heavy metals in plants," "heavy metals in animals," "heavy metals in humans," "heavy metals at mine sites," and "heavy metals effect." The second set of keywords included terms linked to metal pollutants in soil at mining sites, such as "metal contaminants," "contaminants at mining sites," and "metal contaminants in soil". Lastly, the final set of keywords included terms relevant to current health risks around the mining industry, such as "mining health risk" and "mining effects on humans."

Google Scholar, ResearchGate, Elsevier, Springer, and Academia.edu search results were limited to research and review publications authored in English and published between 2014 and 2024. During the initial literature search, all research publications found in databases were selected based on their titles, authors, publication dates, and journals to exclude duplicates. To eliminate irrelevant studies, the remaining papers underwent abstract and full text screening for qualifying criteria.

➢ *Inclusion and Exclusion*

All relevant articles included in this review was classified with respect to: (1) studies that addressed the bioaccumulation of heavy metals in living organisms as their primary topic; (2) studies that reported the metal contaminants in soil at mining sites; (3) studies of heavy metal research per sampling groups at a given mining organization; (4) studies that deliberately tested the health risk of mining sites in various human body systems; (5) studies conducted and published between 2014 and 2024; (6) original studies published as research articles or review articles; (7) original articles with full text and (8) published in English language or have an English translation.

Studies were excluded if they (1) were case series, case reports or narrative reviews; (2) lack corresponding outcome parameters or research data or (3) do not have available full text or (4) no English translation.

➢ *Search Results*

A total of 42 studies were initially identified using Google Scholar, ResearchGate, Elsevier, Springer, and Academia.edu's search terms. This online databases' search results were limited to research and review articles written in English and published between 2014 and 2024, excluding 10 studies from the first search results. Therefore, only 32 research publications remained and were screened according to inclusion criteria. After removing articles based on relevancy, only 25 remained for eligibility. A total of ten literature studies were eventually included in the qualitative analysis for Section 1 of the review, while only fifteen studies were included in the quantitative analysis after further screening and evaluating the eligibility based on the contents of titles and abstracts and the availability of full text materials. The PRISMA flow diagram (Figure 1) illustrates the steps of study selection and findings.

➢ *Data Extraction*

In this paper, 25 studies were chosen from a pool of 42 articles based on the established eligibility criteria. The systematic review encompassed various studies conducted in the Philippines. Pertinent data and information were gathered from these studies throughout the review process.

The information and data extracted from 42 studies include the location of the mining sites, the specific heavy metal content in different flora and fauna species, the concentration of heavy metals in each species, and the health risks associated with the mining sites.

➢ *Statistical Analysis*

After tabulating and assessing the qualitative characteristics of selected studies, literature is further evaluated for eligibility for quantitative and qualitative analysis. Research articles which expressed the concentrations of heavy metals in various mining sites around the Philippines, the health risk, and the accumulation of heavy metals in flora and fauna are incorporated to come up with results that aligned to the objectives.

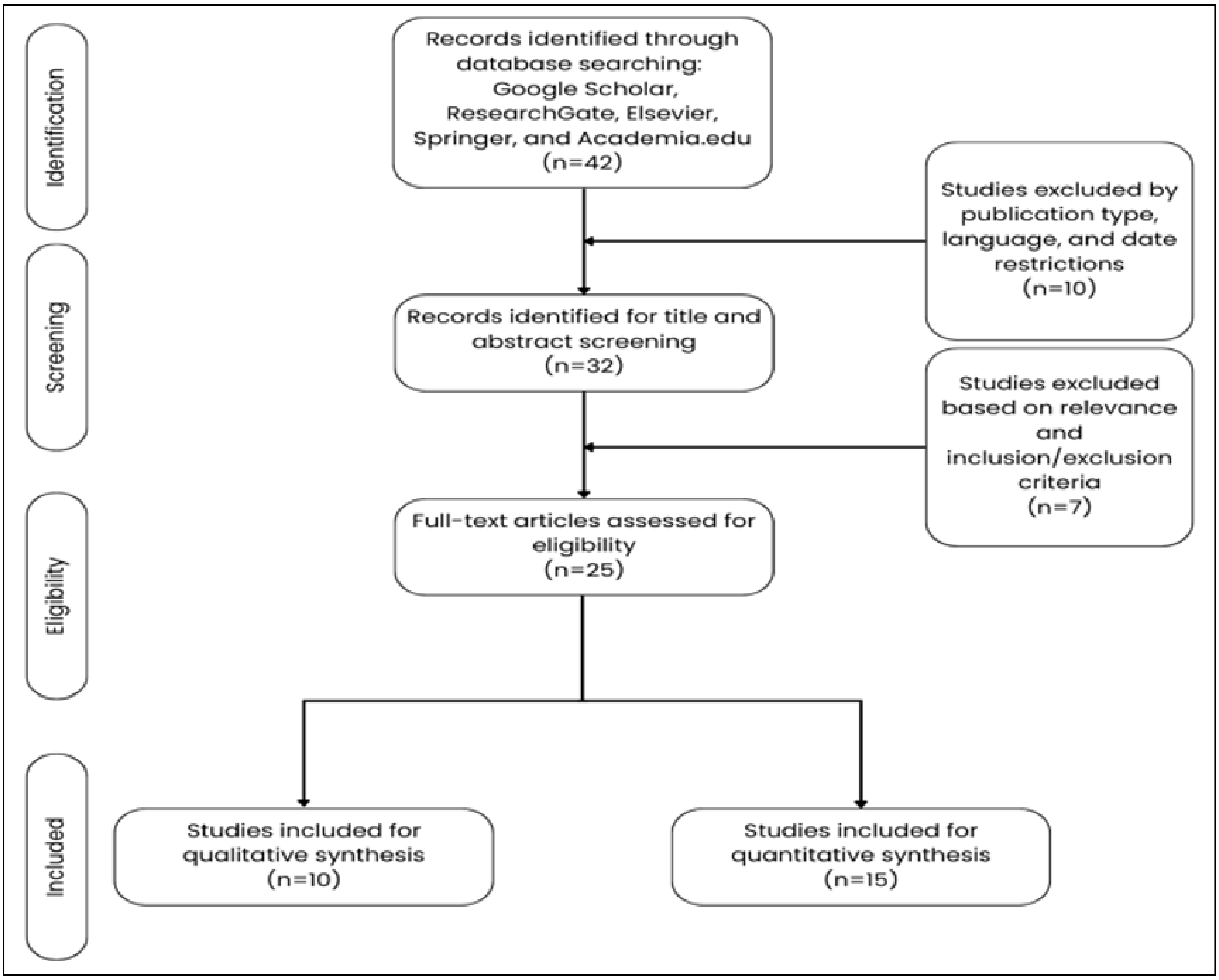


Fig 1 Stages of Study Selection and Results Presented in the PRISMA Flow Diagram

III. RESULTS AND DISCUSSION

- *Quantitative Results:*

From the retrieved studies, 23 species of plants and 21 species of animals, both from Philippines, from 15 publications were identified and discovered together with their corresponding heavy metals and concentrations. 37 sampling groups from 9 mining sites were also evaluated to see the most abundant heavy metal in each group.

The table (See on Pages 5–7) provided offers significant insights into the bioaccumulation of heavy metals in living organisms, particularly plants.

- *Bioaccumulation of Heavy Metals in Flora Species*

Pityrogramma calomelanos a notable species across multiple sites, demonstrates considerable bioaccumulation of heavy metals such as arsenic, copper, and nickel. The roots and leaves of this fern show varying levels of these metals, indicating its effectiveness in sequestering contaminants from the soil. In Site 3, the roots exhibit extremely high copper levels (5924.14), whereas the leaves show significant amounts of both arsenic (44.73) and copper (174.43). This variation highlights the plant's potential in different environmental conditions, making it a versatile candidate for phytoremediation. *Nephrolepis biserrata*, another species with high bioaccumulate properties, particularly accumulates copper in its roots and leaves. At Site 3, the roots contain 5756.07 of copper, showing the plant's substantial capability to extract and store this metal. The presence of these metals primarily in the roots suggests a mechanism of tolerance and detoxification that could be further studied for biotechnological applications in contaminated sites.

- *Specific Accumulation in Species*

Cynodon dactylon shows a significant ability to accumulate copper in its roots (2250.32), while the rice plants from Barangay Tubo-Tubo North and Barangay Lomboy exhibit high levels of nickel and chromium. These rice plants not only accumulate these metals in their plant tissues but also show transfer to grains, which raises concerns about food safety and the need for regular monitoring of crops in contaminated areas.

➤ *Bioaccumulation in Edible Plants*

Edible plants like *Solanum lycopersicum* (tomato), *Solanum melongena* (eggplant), and *Abelmoschus esculentus* (okra) demonstrate significant nickel accumulation in their fruits, with okra showing the highest concentration (848). This indicates potential health risks for human consumption and emphasizes the need for evaluating and mitigating heavy metal uptake in crops grown in contaminated soils.

➤ *Bioaccumulation in Aquatic Plants*

Pistia stratiotes, an aquatic plant, is particularly effective in accumulating mercury in its roots across different sites. The variation in mercury levels (e.g., 0.23 at Site 1) suggests the plant's ability to absorb mercury from water, highlighting its potential use in cleaning mercury-contaminated aquatic systems.

➤ *Zinc Accumulation in Various Species*

Several species, including *Muntingia calabura*, *Mangifera indica*, *Albizia saman*, and *Plectranthus amboinicus*, show significant zinc accumulation in their leaves. *Plectranthus amboinicus* has particularly high zinc levels (91.5), suggesting it could be a useful species for extracting zinc from contaminated soils.

➤ *Bioaccumulation of Heavy Metals in Fauna Species*

The table (See on Pages 8 and 9) provides comprehensive data on the bioaccumulation of heavy metals in various animal species, highlighting significant patterns and implications for ecological health. The species studied include a range of fish (e.g., *Glossogobius giuris, Channa striata*), crustaceans (e.g., *Menippe mercenaria, Scylla serrata*), mollusks (e.g., *Nerita albicilla, Batissa violacea*), among others like *Hylobates agilis* and *Megascolex coeruleus*. The heavy metals measured encompass Arsenic, Copper, Nickel, Mercury, Chromium, Lead, Zinc, and other elements such as Rubidium, Strontium, Manganese, and Zirconium.

Table 1 Bioaccumulation of Heavy Metals in Flora Species

Plant Species	***Heavy Metals***							***Most Abundat Metal(s)***	***Reference***
	Arsenic	*Chromium*	*Copper*	*Lead*	*Mercury*	*Nickel*	*Zinc*		
Cynodon dactylon	Leaves (47.34) Roots (<0.01)	UD	Leaves (20.65) Roots (2250.32)	UD	UD	UD	UD	Arsenic (in leaves) Copper (in roots)	Ancheta et al.
Nephrolepis biserrata	**Site 3** Leaves (153.96) Roots (<0.01)	UD	**Site 3** Leaves (191.41) Roots (5756.07)	UD	UD	UD	UD	Copper (in leaves) Copper (in roots)	
Pityrogramma calomelanos	**Site 1** Leaves (50.52) Roots (<0.01) **Site 2** Leaves (280.18) Roots (<161.82) **Site 3** Leaves (44.73) Roots (<0.01)	UD	**Site 1** Leaves (181.31) Roots (1694.46) **Site 2** Leaves (34.67) Roots (578.08) **Site 3** Leaves (174.43) Roots (5924.14)	UD	UD	UD	UD	Copper (in leaves) Copper (in roots)	
Abelmoschus esculentus	UD	110	UD	UD	UD	848	UD	Nickel (in the fruit)	Bacani and Farin
Ipomoea batatas	UD	58	UD	UD	UD	203	UD	Nickel (in the fruit)	
Rice Grain	UD	**Brgy. Lomboy** 40 **Brgy. Tubo-Tubo** 31	UD	UD	UD	**Brgy. Lomboy** 47 **Brgy. Tubo-Tubo** 9	UD	Chromium	
Rice Plant	UD	**Brgy. Lomboy** 277 **Brgy. Tubo-Tubo** 107	UD	UD	UD	**Brgy. Lomboy** 273 **Brgy. Tubo-Tubo** 208	UD	Nickel	
Solanum lycopersicum	UD	164	UD	UD	UD	551	UD	Nickel (in the fruit)	
Solanum melongena	UD	50	UD	UD	UD	216	UD	Nickel (in the fruit)	
Pistia stratiotes	UD	UD	UD	UD	**Site 1** 0.23 **Site 2** 0.08 **Site 3** 0.18	UD	UD	Mercury (in roots)	Denetillo and Goloran

Note: The unit used in the table of data is mg/kg. UD indicates there were unavailable data from the reviewed literature(s); Q stands for quarter; No ID was used by the literature researcher for an unidentified species; <LD refers to the low detection limit; and ND indicates no metal detected.

Plant Species		***Heavy Metals***							***Most Abundant Metal(s)***	***Reference***
		Arsenic	*Chromium*	*Copper*	*Lead*	*Mercury*	*Nickel*	*Zinc*		
Albizia saman		UD	UD	Butansapa 49.12 Mangyan mababad 133.9	UD	UD	UD	UD	Copper (in the fruit and leaves)	Gigantone et al.
Cassia alata		UD	UD	**Nangka II** 334.58	UD	UD	UD	UD	Copper (in the fruit and leaves)	
Justicia gendarussa		UD	UD	**Padjao Falls** 46.73	UD	UD	UD	UD	Copper (in the fruit and leaves)	
Nephrolepis biserrata		UD	UD	**Bocboc** 225.76 **Padjao Falls** 34.06	UD	UD	UD	UD	Copper (in leaves)	
No ID		UD	UD	**Bocboc** 52.83	UD	UD	UD	UD	Copper (in the fruit and leaves)	
Pityrogramma calomelanos		UD	UD	**Mangyan mababad** 133.9	UD	UD	UD	UD	Copper (in leaves)	
Quisqualis indica		UD	UD	**Nangka II** 85.86	UD	UD	UD	UD	Copper (in the fruit and leaves)	
Sargassum polycystum	Q1	UD	UD	**Site 1:** 4.263 ± 0.224 **Site 2:** 6.302 ± 0.864 **Site 3:** 3.901 ± 0.208	**Site 1:** 19.553 ± 1.396 **Site 2:** 6.926 ± 1.123 **Site 3:** 15.326 ± 1.108	UD	**Site 1:** 18.357 ± 0.972 **Site 2:** 138.189 ± 17.372 **Site 3:** 21.025 ± 0.847	UD	Nickel (in the stem and leaves)	Corales-Ultra et al.
	Q2	UD	UD	**Site 1:** 4.797 ± 0.215 **Site 2:** 4.336 ± 0.138 **Site 3:** 3.281 ± 0.176	**Site 1:** 10.928 ± 0.584 **Site 2:** 11.242 ± 1.279 **Site 3:** 21.579 ± 0.730	UD	**Site 1:** 24.476 ± 0.509 **Site 2:** 75.458 ± 10.057 **Site 3:** 16.143 ± 0.365	UD		
	Q3	UD	UD	**Site 1:**	**Site 1:** < LD	UD	**Site 1:**	UD		

				3.558 ± 0.212 **Site 2:** 4.073 ± 0.176 **Site 3:** 2.825 ± 0.110	**Site 2:** < LD **Site 3:** < LD		22.516 ± 2.720 **Site 2:** 120.686 ± 10.017 **Site 3:** 13.630 ± 7.341			
	Q4	UD	UD	**Site 1:** 5.016 ± 0.176 **Site 2:** 4.074 ± 0.039 **Site 3:** 2.944 ± 0.020	**Site 1:** < LD **Site 2:** < LD **Site 3:** < LD	UD	**Site 1:** 42.000 ± 0.679 **Site 2:** 160.120 ± 3.375 **Site 3:** 14.129 ± 0.524	UD		

Plant Species	***Heavy Metals***							***Most Abundant Metal(s)***	***Reference***
	Arsenic	*Chromium*	*Copper*	*Lead*	*Mercury*	*Nickel*	*Zinc*		
Albizia saman	UD	ND	7.2 ± 0.2	1.3 ± 0.0	UD	UD	13.0 ± 0.0	Zinc (in leaves)	Navarette et al.
Colocasia esculenta	UD	ND	16.3 ± 2.8	ND	UD	UD	80.5 ± 7.8	Zinc (in leaves)	
Ipomoea batatas	UD	ND	13.9 ± 0.9	1.2 ± 0.4	UD	UD	25.0 ± 0.0	Zinc (in leaves)	
Mangifera indica	UD	ND	5.2 ± 4.2	1.2 ± 0.1	UD	UD	20.0 ± 10.4	Zinc (in leaves)	
Manihot esculenta	UD	ND	7.6 ± 4.3	0.7 ± 0.1	UD	UD	59.2 ± 42.8	Zinc (in leaves)	
Moringa oleifera	UD	ND	11.5 ± 1.3	0.5 ± 0.0	UD	UD	31.0 ± 0.0	Zinc (in leaves)	
Muntingia calabura	UD	ND	8.8 ± 1.6	1.6 ± 0.7	UD	UD	37.5 ± 2.1	Zinc (in leaves)	
Musa x paradisiaca	UD	ND	18.9 ± 1.0	1.5 ± 0.0	UD	UD	19.5 ± 0.7	Zinc (in leaves)	
Plectranthus amboinicus	UD	0.85 ± 0.07	20.4 ± 0.2	3.4 ± 0.2	UD	UD	91.5 ± 7.8	Zinc (in leaves)	
Pteocarpus indicus	UD	ND	3.9 ± 0.4	0.7 ± 0.0	UD	UD	11.5 ± 0.7	Zinc (in leaves)	

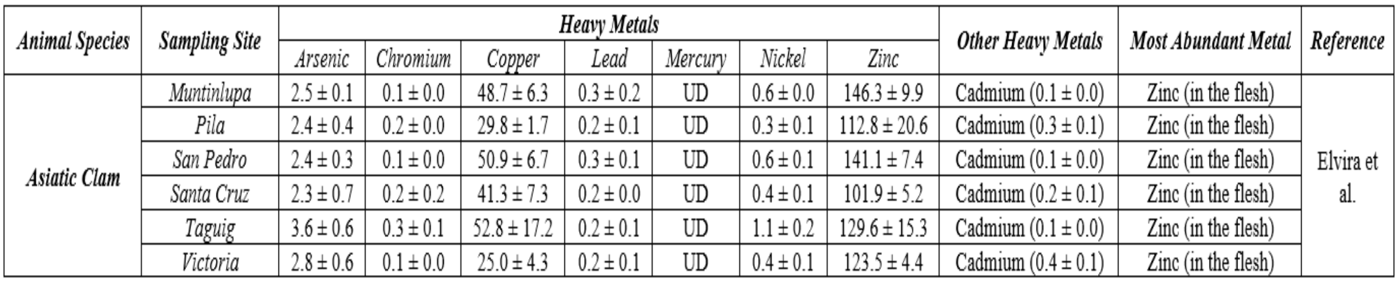
Table 2 Biocaccumulation of Heavy Metals in Fauna Species

Animal Species	***Heavy Metals***							***Other Heavy Metals***	***Most Abundant Metal***	***Reference***
	Arsenic	*Chromium*	*Copper*	*Lead*	*Mercury*	*Nickel*	*Zinc*			
Anguilla marmorata	UD	UD	UD	<0.15	<0.02	UD	UD	Cadmium (<0.02)	Lead	Ebol et al.
Channa striata	UD	UD	UD	0.49 ± 0.00	<0.02	UD	UD	Cadmium (<0.02)	Lead	
Clarias batrachus	UD	UD	UD	<0.15	<0.02	UD	UD	Cadmium (<0.02)	Lead	
Corbicula fluminea	UD	UD	UD	<0.15	<0.02	UD	UD	Cadmium (<0.02)	Lead	
Cyprinus carpio	UD	UD	UD	<0.15	<0.02	UD	UD	Cadmium (<0.02)	Lead	

Glossogobius giuris	UD	UD	UD	0.35 ± 0.00	<0.02	UD	UD	Cadmium (<0.02)	Lead	
Hylobates agilis	UD	UD	UD	<0.15	<0.02	UD	UD	Cadmium (<0.02)	Lead	
Oreochromis niloticus	UD	UD	UD	0.27 ± 0.01	<0.02	UD	UD	Cadmium (<0.02)	Lead	
Sundathelphusa sp.	UD	UD	UD	0.60 ± 0.05	<0.02	UD	UD	Cadmium (<0.02)	Lead	
V. angularis	UD	UD	UD	0.52 ± 0.00	<0.02	UD	UD	Cadmium (<0.02)	Lead	
Batissa violacea	14.33 ± 3.18	532.00 ± 18.73	97.67 ± 7.24	0.59 ± 0.04	UD	29.30 ± 3.21	483.33 ± 22.38	Manganese (706.67 ± 21.55), Rubidium (3.33 ± 2.38), Strontium (14.67 ± 1.16), Zirconium (2.00 ± 0.83)	Manganese	Cabahug et al.
Macrobrachium rosenbergii	UD	554.00 ± 6.28	41.00 ± 3.26	0.25 ± 0.08	UD	12.30 ± 1.48	111.67 ± 8.36	Manganese (669.33 ± 10.25), Rubidium (26.67 ± 2.14), Strontium (22.33 ± 5.65)	Manganese	
Menippe mercenaria	UD	556.00 ± 27.39	52.00 ± 12.36	0.31 ± 0.16	UD	16.83 ± 1.85	43.33 ± 10.28	Manganese (698.67 ± 18.23), Rubidium (9.00 ± 3.40)	Manganese	
Nerita albicilla	8.33 ± 3.67	557.67 ± 22.73	35.00 ± 16.21	0.21 ± 0.19	UD	10.50 ± 6.22	77.00 ± 14.22	Manganese (729.00 ± 20.24), Rubidium (9.00 ± 3.40), Strontium (2.33 ± 0.12), Zirconium (3.00 ± 0.54)	Manganese	
Scylla serrata	14.00 ± 0.27	508.00 ± 2.44	118.67 ± 10.28	0.71 ± 0.14	UD	25.79 ± 2.74	331.00 ± 10.22	Manganese (688.00 ± 6.72), Rubidium (6.67 ± 2.14),	Manganese	

								Strontium (60.67 ± 7.24), Zirconium (5.67 ± 1.28)		
Telescopium telescopium	18.33 ± 2.25	510.00 ± 12.32	56.67 ± 8.32	0.34 ± 0.08	UD	18.13 ± 2.56	162.33 ± 6.23	Manganese (660.33 ± 12.44), Rubidium (26.33 ± 1.26), Strontium (4.67 ± 0.26)	Manganese	
Megascolex coeruleus	UD	UD	**Bocboc** 219.42	UD	UD	UD	UD	UD	Copper	Gigantone et al.
Pagarus sp.	UD	UD	1862.89	UD	UD	UD	UD	UD	Copper	
Poecilia sphenops.	UD	UD	**Bocboc** 121.19 **Padjao falls** 116.37	UD	UD	UD	UD	UD	Copper	
Potamalpheops sp.	UD	UD	109.57	UD	UD	UD	UD	UD	Copper	

Note: The unit used in the table of data is mg/kg. UD indicates there were unavailable data from the reviewed literature(s).



Animal Species	*Sampling Site*	*Heavy Metals*							*Other Heavy Metals*	*Most Abundant Metal*	*Reference*
		Arsenic	*Chromium*	*Copper*	*Lead*	*Mercury*	*Nickel*	*Zinc*			
Asiatic Clam	*Muntinlupa*	2.5 ± 0.1	0.1 ± 0.0	48.7 ± 6.3	0.3 ± 0.2	UD	0.6 ± 0.0	146.3 ± 9.9	Cadmium (0.1 ± 0.0)	Zinc (in the flesh)	Elvira et al.
	Pila	2.4 ± 0.4	0.2 ± 0.0	29.8 ± 1.7	0.2 ± 0.1	UD	0.3 ± 0.1	112.8 ± 20.6	Cadmium (0.3 ± 0.1)	Zinc (in the flesh)	
	San Pedro	2.4 ± 0.3	0.1 ± 0.0	50.9 ± 6.7	0.3 ± 0.1	UD	0.6 ± 0.1	141.1 ± 7.4	Cadmium (0.1 ± 0.0)	Zinc (in the flesh)	
	Santa Cruz	2.3 ± 0.7	0.2 ± 0.2	41.3 ± 7.3	0.2 ± 0.0	UD	0.4 ± 0.1	101.9 ± 5.2	Cadmium (0.2 ± 0.1)	Zinc (in the flesh)	
	Taguig	3.6 ± 0.6	0.3 ± 0.1	52.8 ± 17.2	0.2 ± 0.1	UD	1.1 ± 0.2	129.6 ± 15.3	Cadmium (0.1 ± 0.0)	Zinc (in the flesh)	
	Victoria	2.8 ± 0.6	0.1 ± 0.0	25.0 ± 4.3	0.2 ± 0.1	UD	0.4 ± 0.1	123.5 ± 4.4	Cadmium (0.4 ± 0.1)	Zinc (in the flesh)	

- *Findings and Patterns*

Copper emerges as a highly accumulated metal, particularly in species such as *Pagurus sp.*, with a staggering concentration of 1862.89 mg/kg. This contrasts sharply with lower concentrations found in Asiatic clam (Santa Cruz) at 2.3 ± 0.7 mg/kg, indicating a wide variability in copper bioaccumulation across different species. Lead and Cadmium, while generally present in lower concentrations, consistently appear across multiple species. Notably, *Telescopium telescopium* exhibits a significant lead concentration of 510.00 ± 12.32 mg/kg. Manganese stands out as a frequently abundant metal, particularly in *Nerita albicilla* with 729.00 ± 20.24 mg/kg, suggesting a high capacity for manganese accumulation in certain organisms.

- *Specific Accumulation in Species*

The data reveals considerable variability in metal concentrations among species, highlighting species-specific bioaccumulation capacities. For example, Copper levels in *Poecilia sphenops* vary significantly across different locations, reflecting local environmental conditions and potential contamination sources. High levels of multiple metals in species like *Telescopium telescopium*, *Nerita albicilla,* and *Batissa violacea* suggest these organisms are particularly exposed to or capable of accumulating significant amounts of heavy metals.

- *Environmental and Biological Implications*

The bioaccumulation of heavy metals such as Lead and Cadmium, even at low concentrations, poses substantial toxicological risks to both the organisms and their ecosystems. Elevated Copper levels, as seen in *Pagurus sp.,* may indicate contamination due to anthropogenic activities, necessitating urgent environmental intervention. While Manganese is essential in trace amounts, its high concentrations in multiple species could lead to toxic effects, indicating possible overexposure in their habitats.

- *Metal Contaminants in Soil*

In several studies, nine mining sites in various parts of the Philippines were identified as having high levels of heavy metal contaminants in the nearby communities' soil. The data from these studies was assessed against the soil quality standards (SQS) from Tanzania. Nickel was the most frequently mentioned heavy metal, present in 4 out of 9 mining sites, with the highest concentration recorded at 8,448.03 mg/kg. The SQS stipulates that the permitted nickel concentration in soils should not exceed 100 mg/kg, indicating severe nickel contamination in the area. Chromium and copper followed, with concentrations of 17,712 ± 15,394 mg/kg and 2,972.00 mg/kg, respectively. According to the SQS, the allowable concentration for chromium is 100 mg/kg, therefore showing non-compliance in the area. Likewise, the area surpassed the regulation for copper, which permits a concentration of 200 mg/kg. (See on Pages 12–14).

- *Qualitative Results:*

Ten gathered papers were used to investigate the health impacts of heavy metals from mining sites to human beings. Seven mining sites were used. Five of them have been identified as abandoned or no longer functional, while two remain operational despite their severe impact on the environment and humans. Six body systems were considered while assessing risks to health in the study.

The table (See on Pages 15 and 16) displays the current mining status of seven mining sites as well as how heavy metals affect the six considered human body systems.

- *Mining Health Risk Assessment*

The mining operations in various regions, including Santa Cruz, Zambales; Palawan; Carrascal, Surigao Del Sur; and the six municipalities of Marinduque, have either been suspended, abandoned, or remain active despite the presence of heavy metals such as Nickel, Chromium, Mercury, Lead, Cadmium, Manganese, Zinc, Copper, Iron, Arsenic, Barium, and Aluminum.

These contaminants have been linked to a wide range of health issues affecting multiple bodily systems. In the respiratory system, heavy metal exposure can lead to lung cancer, asthma, lung irritation, and other respiratory problems. The digestive system is also severely impacted, causing symptoms like diarrhea, abdominal discomfort, stomach cancer, typhoid, and even mild stomachaches from consuming contaminated vegetables. The integumentary system may suffer from severe skin issues, including skin allergies, rashes, skin cancer (Bowen's Disease), hyperkeratosis, and scaling. The cardiovascular system can be affected by diseases such as blood cancer, anemia, hypertension, decreased blood pressure, and various cardiovascular diseases. The urinary system is at risk of kidney damage, urinary tract infections, urinary retention, increased urinary frequency, and bladder cancer. Additionally, the neurological system can experience developmental delays, nervous system damage, tremors, difficulty walking, headaches, and mental health issues such as anxiety and depression.

These widespread health impacts highlight the severe consequences of heavy metal contamination from both active and abandoned mining operations, underscoring the critical need for addressing environmental and public health concerns in these communities.

IV. CONCLUSION

This systematic review investigated the bioaccumulation of heavy metals in living organisms surrounding mining sites and the associated health risks. Based on the results obtained, it revealed several key findings such as the prevalent heavy metals, bioaccumulation concerns, and knowledge gap bridged.

This study sheds light on the dangers of bioaccumulation and pinpoints the most problematic heavy metals. These findings underscore the urgent need for stricter regulations and a shift towards more sustainable practices in the mining industry. Additionally, ongoing research should prioritize the development of effective remediation techniques. By reducing the environmental burden of heavy metal contamination, we can safeguard the health of surrounding ecosystems.

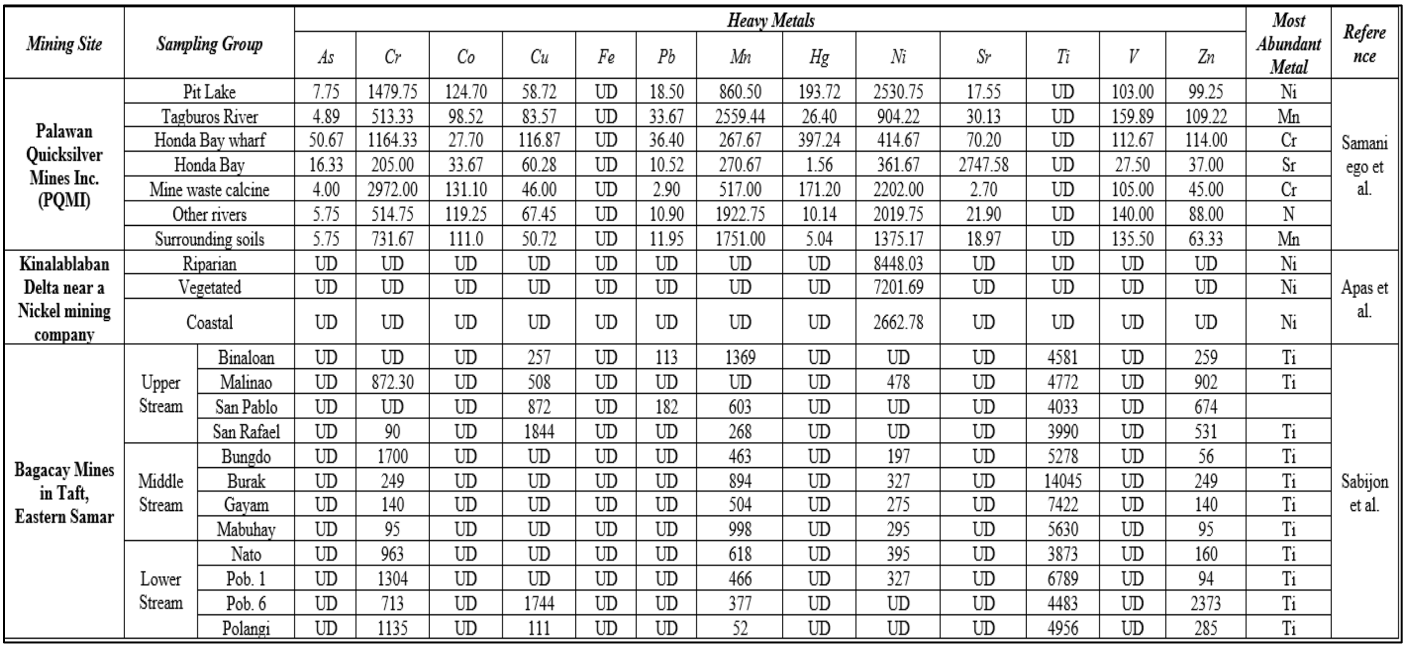
Highlights the effectiveness of certain plant species like *Pityrogramma calomelanos* and *Nephrolepis biserrata* in accumulating arsenic, copper, and nickel, suggesting their potential for phytoremediation. Concerns arise regarding metal accumulation in crops and edible plants, emphasizing the importance of ongoing monitoring for food safety. Aquatic plants like *Pistia stratiotes* show promise in mercury accumulation, while species like *Plectranthus amboinicus* exhibit potential for zinc extraction from contaminated soils. Additionally, copper shows wide variability across species, with lead, cadmium, and manganese consistently appearing at notable concentrations. Specific species demonstrate significant metal accumulation, underscoring the toxicological risks associated with heavy metal bioaccumulation and the need for environmental intervention and monitoring to protect both organisms and ecosystems.

Nine mining sites were identified based on the review of relevant research papers, serving as foundational references for this study. Upon assessing mining sites across the Philippines, notably high concentrations of heavy metal contaminants, including Nickel, Chromium, and Copper, were identified. Importantly, these contaminants surpassed the allowable concentration levels outlined in the Soil Quality Standards (SQS) of Tanzania.

Based on the findings, the impact of heavy metals from mining sites on human health is very alarming. These contaminants offer a substantial risk, potentially causing a variety of health issues. Mitigating these dangers through tougher restrictions and better mining techniques is critical for protecting the health of residents near these sites. Additional research is also required to fully understand the long-term impacts of exposure and to design appropriate public health solutions.

To further our understanding, future research should prioritize three key areas. First, conducting site-specific studies can reveal unique bioaccumulation patterns at different mines. Second, investigating the effectiveness of various remediation strategies will be crucial for mitigating existing contamination. Finally, exploring potential synergistic effects of different heavy metals on organisms and ecosystems will provide a more holistic view of the ecological risks. By pursuing research in these areas, we can minimize the environmental and health impacts of mining, ultimately promoting the sustainability of our ecosystems.

Table 3 Metal Contaminants in Soil



Mining Site	*Sampling Group*		*Heavy Metals*													*Most Abundant Metal*	*Reference*
			As	*Cr*	*Co*	*Cu*	*Fe*	*Pb*	*Mn*	*Hg*	*Ni*	*Sr*	*Ti*	*V*	*Zn*		
Palawan Quicksilver Mines Inc. (PQMI)	Pit Lake		7.75	1479.75	124.70	58.72	UD	18.50	860.50	193.72	2530.75	17.55	UD	103.00	99.25	Ni	Samaniego et al.
	Tagburos River		4.89	513.33	98.52	83.57	UD	33.67	2559.44	26.40	904.22	30.13	UD	159.89	109.22	Mn	
	Honda Bay wharf		50.67	1164.33	27.70	116.87	UD	36.40	267.67	397.24	414.67	70.20	UD	112.67	114.00	Cr	
	Honda Bay		16.33	205.00	33.67	60.28	UD	10.52	270.67	1.56	361.67	2747.58	UD	27.50	37.00	Sr	
	Mine waste calcine		4.00	2972.00	131.10	46.00	UD	2.90	517.00	171.20	2202.00	2.70	UD	105.00	45.00	Cr	
	Other rivers		5.75	514.75	119.25	67.45	UD	10.90	1922.75	10.14	2019.75	21.90	UD	140.00	88.00	N	
	Surrounding soils		5.75	731.67	111.0	50.72	UD	11.95	1751.00	5.04	1375.17	18.97	UD	135.50	63.33	Mn	
Kinalablaban Delta near a Nickel mining company	Riparian		UD	UD	UD	UD	UD	UD	UD	UD	8448.03	UD	UD	UD	UD	Ni	Apas et al.
	Vegetated		UD	UD	UD	UD	UD	UD	UD	UD	7201.69	UD	UD	UD	UD	Ni	
	Coastal		UD	UD	UD	UD	UD	UD	UD	UD	2662.78	UD	UD	UD	UD	Ni	
Bagacay Mines in Taft, Eastern Samar	Upper Stream	Binaloan	UD	UD	UD	257	UD	113	1369	UD	UD	UD	4581	UD	259	Ti	Sabijon et al.
		Malinao	UD	872.30	UD	508	UD	UD	UD	UD	478	UD	4772	UD	902	Ti	
		San Pablo	UD	UD	UD	872	UD	182	603	UD	UD	UD	4033	UD	674		
		San Rafael	UD	90	UD	1844	UD	UD	268	UD	UD	UD	3990	UD	531	Ti	
	Middle Stream	Bungdo	UD	1700	UD	UD	UD	UD	463	UD	197	UD	5278	UD	56	Ti	
		Burak	UD	249	UD	UD	UD	UD	894	UD	327	UD	14045	UD	249	Ti	
		Gayam	UD	140	UD	UD	UD	UD	504	UD	275	UD	7422	UD	140	Ti	
		Mabuhay	UD	95	UD	UD	UD	UD	998	UD	295	UD	5630	UD	95	Ti	
	Lower Stream	Nato	UD	963	UD	UD	UD	UD	618	UD	395	UD	3873	UD	160	Ti	
		Pob. 1	UD	1304	UD	UD	UD	UD	466	UD	327	UD	6789	UD	94	Ti	
		Pob. 6	UD	713	UD	1744	UD	UD	377	UD	UD	UD	4483	UD	2373	Ti	
		Polangi	UD	1135	UD	111	UD	UD	52	UD	UD	UD	4956	UD	285	Ti	

Note: The unit used in the table of data is mg/kg. UD indicates there were unavailable data from the reviewed literature(s).

Mining Site	***Sampling Group***	***Heavy Metals***													***Most Abundant Metal***	***Reference***
		As	*Cr*	*Co*	*Cu*	*Fe*	*Pb*	*Mn*	*Hg*	*Ni*	*Sr*	*Ti*	*V*	*Zn*		
Maguilaguila and Tapian Mining Pits in Marinduque	Boac	UD	854 ± 365	UD	9159 ± 10727	772972 ± 116476	UD	25597 ± 20945	UD	UD	UD	UD	UD	3734 ± 2083	Fe	Nolos et al.
	Buenavista	UD	1695 ± 921	UD	2090 ± 827	759560 ± 325617	UD	60550 ± 52526	UD	UD	UD	UD	UD	3734 ± 2083	Fe	
	Gasan	UD	2466 ± 1380	UD	UD	1083607 ± 616615	UD	29238 ± 9882	UD	3216 ± 3412	UD	UD	UD	2291 ± 494	Fe	
	Mogpog	UD	UD	UD	17712 ± 15394	783457 ± 133191	1291 ± 431	31893 ± 9421	UD	UD	UD	UD	UD	6161 ± 2962	Fe	
	Sta. Cruz	UD	1257	UD	3506 ± 857	50522 ± 38289	UD	50522	UD	UD	UD	UD	UD	2760	Fe	

				± 917					± 38289						± 1014		
	Torrijos		UD	1409 ± 533	UD	2807 ± 1328	38298 ± 15042	UD	38298 ± 15042	UD	UD	UD	UD	UD	2790 ± 876	Fe	
Abandoned Mine in Municini Island, Guian, Eastern Samar	Seawater	Q1	UD	UD	UD	**Site 1:** 0.513 ± 0.010 **Site 2:** 0.492 ± 0.008 **Site 3:** 0.520 ± 0.023	UD	**Site 1:** 1.394 ± 0.062 **Site 2:** 1.353 ± 0.093 **Site 3:** 1.508 ± 0.120	UD	UD	**Site 1:** 0.314 ± 0.081 **Site 2:** 0.242 ± 0.007 **Site 3:** 0.628 ± 0.281	UD	UD	UD	UD	Cu	Corales-Ultra et al.
		Q2	UD	UD	UD	**Site 1:** 0.473 ± 0.003 **Site 2:** 0.485 ± 0.011 **Site 3:** 0.480 ± 0.006	UD	**Site 1:** 1.289 ± 0.074 **Site 2:** 0.974 ± 0.114 **Site 3:** 0.846 ± 0.089	UD	UD	**Site 1:** 0.242 ± 0.007 **Site 2:** 0.256 ± 0.053 **Site 3:** 0.167 ± 0.005	UD	UD	UD	UD	Pb	
		Q3	UD	UD	UD	**Site 1:** 0.457 ± 0.004	UD	**Site 1:** 0.828 ± 0.060	UD	UD	**Site 1:** 0.152 ± 0.009	UD	UD	UD	UD	Pb	

						Site 2: 0.457 ± 0.003 **Site 3:** 0.458 ± 0.015		**Site 2:** 0.665 ± 0.046 **Site 3:** 0.592 ± 0.095			**Site 2:** 0.134 ± 0.009 **Site 3:** 0.148 ± 0.009						
		Q4	UD	UD	UD	**Site 1:** 0.531 ± 0.005 **Site 2:** 0.498 ± 0.003 **Site 3:** 0.476 ± 0.003	UD	**Site 1:** 0.801 ± 0.034 **Site 2:** 0.893 ± 0.067 **Site 3:** 0.388 ± 0.058	UD	UD	**Site 1:** 0.124 ± 0.008 **Site 2:** 0.155 ± 0.010 **Site 3:** 0.122 ± 0.008	UD	UD	UD	UD	Pb	

Mining Site	***Sampling Group***	***Heavy Metals***													***Most Abundant Metal***	***Reference***
		As	***Cr***	***Co***	***Cu***	***Fe***	***Pb***	***Mn***	***Hg***	***Ni***	***Sr***	***Ti***	***V***	***Zn***		
Mining Site in Pagatban River	Bottom sediments of Pagatban River	UD	UD	UD	222.4–242.8	UD	UD	<1–5.8	UD	UD	UD	UD	UD	41.8–51.4	Cu	Guino-o II et al.
Small-scale mining area in Sibutad, Southern Mindanao	Site 1	UD	UD	UD	84.8 ± 113	2597 ± 703	27.6 ± 8.5	UD	UD	UD	UD	UD	UD	47.7 ± 73.4	Fe	Martinez et al.
	Site 2	UD	UD	UD	35.0 ± 11.5	2346 ± 413	32.3 ± 6.95	UD	2.00 ± 1.56	UD	UD	UD	UD	33.3 ± 16.1	Fe	

	Site 3		UD	UD	UD	45.5 ± 31.2	2634 ± 770	27.5 ± 13.7	UD	1.34 ± 083	UD	UD	UD	UD	24.6 ± 21	Fe	
	Site 4		UD	UD	UD	85.9 ± 47.2	2684 ± 861	136 ± 78	UD	38.4 ± 43.3	UD	UD	UD	UD	65.4 ± 26.9	Fe	
	Site 5		UD	UD	UD	59.4 ± 35	2098 ± 781	48.9 ± 11.6	UD	1.51 ± 1.63	UD	UD	UD	UD	30 ± 7.8	Fe	
Sites near mining areas with mine tailing deposits	Sta. Cruz, Zambales		<9.0	1126.5	UD	<25.0	UD	UD	UD	>8.0	2624.1	UD	UD	UD	<15.0	Ni	Magahud et al.
	Sipalay City, Negros Occidental		11.4	36.8	UD	986.3	UD	UD	UD	UD	<50.0	UD	UD	UD	60.0	Cu	
Mining areas near Sta. Cruz, Zambales	Pre-sampling	Brgy. Tubo-Tubo North	UD	797	UD	UD	UD	UD	UD	UD	3.230	UD	UD	UD	UD	Cr	Bacani and Farin
		Brgy. Lomboy	UD	1.390	UD	UD	UD	UD	UD	UD	5.670	UD	UD	UD	UD	Ni	
	Post-Sampling	Brgy. Tubo-Tubo	UD	783	UD	UD	UD	UD	UD	UD	2.370	UD	UD	UD	UD	Cr	
		Brgy. Lomboy	UD	1.170	UD	UD	UD	UD	UD	UD	3.090	UD	UD	UD	UD	Ni	

Table 4 Health Risk Assessment in Three (3) Mining Sites in the Philippines

Mining Site Location	***Mining Site Status***	***Heavy Metals Present***	***Health Risk in Human Body System***		***References***
Santa Cruz, Zambales	Operating but suspended	Nickel Chromium	*Respiratory System*	• Coughing • Asthma • Difficulty in breathing • Tight chest • Frequent sneezing	Farin (2018)
			Digestive System	• Diarrhea • Stomachache • Nausea and vomiting	
			Integumentary System	• Severe itchiness of the skin • Skin rashes	
			Cardiovascular System	• Hypertension • Decreased blood pressure • Tight chest Increased heartbeat and palpitations	
			Urinary System	• Urinary Tract Infection • Urinary frequency • Urinary retention	

Mining Site Location	***Mining Site Status***	***Heavy Metals Present***	***Health Risk in Human Body System***		***References***
			Neurological System	• Headache • Dizziness	
Palawan	Abandoned	Mercury Lead Cadmium Nickel Chromium	*Respiratory System*	• Respiratory problems	Diwa et al. (2023)
			Digestive System		
			Integumentary System	• Skin allergies	
			Cardiovascular System	• Anemia	
			Urinary System	• Kidney issues	
			Neurological System	Development problems in children Worsening mental health such as anxiety and depression	
Carrascal, Surigao Del Sur	Operating	Chromium Nickel Manganese Zinc	*Respiratory System*	• Lung cancer • Respiratory problems	Arreza et al. (2022)
			Digestive System		
			Integumentary System	• Skin allergies	
			Cardiovascular System		
			Urinary System		
			Neurological System	• Tremors • Difficulty in walking	
Marinduque	Abandoned	Arsenic Lead	*Respiratory System*	• Lung irritation • Asthma	Iggual et al. (n.d.)
			Digestive System	• Diarrhea • Typhoid	
			Integumentary System	• Rashes • Skin problems	
			Cardiovascular System	• Blood cancer • Anemia	
			Urinary System		
			Neurological System	• Developmental delays Nervous System damage in children and adults Worsening mental health such as anxiety and stress	
Taft River Basin, Eastern Samar	Abandoned	Cadmium Lead Copper Chromium Zinc Nickel Arsenic Aluminum Iron	*Respiratory System*		Cabahug (2022)
			Digestive System	• Mild stomachache	
			Integumentary System		
			Cardiovascular System	• Anemia	
			Urinary System	• Kidney damage	
			Neurological System	• Developmental delays • Nervous System damage	
6 Municipalities	Operating	Cadmium Chromium	*Respiratory System*		Nolos et al. (2022)

of Marinduque: Mogpog Boac Santa Cruz Torrijos Gasan Buenavista		Copper Iron Manganese Nickel Lead Zinc	*Digestive System*	Cancer due to consuming vegetables from a soil with heavy metal	
			Integumentary System		
			Cardiovascular System		
			Urinary System		
			Neurological System		
Marinduque Province	Abandoned	Arsenic Barium Copper Iron Lead Manganese Nickel Zinc	*Respiratory System*	• Lung cancer	Senoro et al. (2022)
			Digestive System	• Severe watery diarrhea • Abdominal discomfort • Stomach cancer	
			Integumentary System	• Skin cancer (Bowen's Disease) • Hyperkeratosis and scaling	
			Cardiovascular System	• Cardiovascular diseases	
			Urinary System	• Bladder cancer	
			Neurological System	• Headaches • Dullness • Restlessness and irritability	

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