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FROM IRRIGATION TO TABLE: A SYSTEMATIC REVIEW OF HUMAN HEALTH RISKS FROM HEAVY METAL CONTAMINATION IN PHILIPPINE AGRICULTURAL WATER AND ITS IMPLICATIONS TO FOOD SAFETY

Divina Maris Mande[1]
Angel Ventura[1]
Jose Adrian R. Daguison[1]
Gecelene Estorico[1,2]
Civil and Allied Department; Environmental Science and Chemical Technology Department
[1]Technological University of the Philippines—Taguig, Taguig, Metro Manila 1630 Philippines [2]De La Salle University – Dasmariñas, DBB-B, 4115 West Ave, Dasmariñas,

ABSTRACT
This systematic review evaluates the current state of heavy metal contamination in Philippine agricultural water and the associated risks to food safety and human health. By synthesizing data from multiple regions, the study identifies primary geographic hotspots driven by mining legacies, industrial runoff, and urban wastewater. Concentrations of key metals, specifically Lead (Pb), Cadmium (Cd), Arsenic (As), Mercury (Hg), and Chromium (Cr) were quantified and compared against DENR Administrative Order 2016-08 and WHO/FAO standards. Results reveal critical violations, notably Arsenic levels in Laguna (0.656 mg/L) exceeding local standards by over 30 times and Lead levels in staple brown rice (>0.2 mg/kg) surpassing international safety limits. While non-carcinogenic risks, measured via Target Hazard Quotients (THQ), generally remain within safe thresholds, the Total Carcinogenic Risk (TCR) in several regions exceeds the 1×10^{-4} safety limit, indicating a significant long-term cancer risk. The findings underscore the urgent need for stricter water quality monitoring and the implementation of remediation strategies, such as phytoremediation, to safeguard the Philippine food chain.

Keywords:
Heavy Metals, Agricultural Water, Food Safety, Health Risk Assessment, Target Hazard Quotient, Estimated Daily Intake, Irrigation Systems, Bioaccumulation, Phytoremediation.

INTRODUCTION
The intersection of water quality and agricultural productivity is a critical pillar of food security, yet it is increasingly compromised by heavy metal contamination in the Philippine landscape. The reliance on diverse water sources for irrigation ranging from major river systems and lakes to groundwater, has exposed the agricultural sector to a suite of persistent environmental pollutants (Singh et al., 2022). Heavy metals such as lead (Pb), cadmium (Cd), mercury (Hg), and chromium (Cr) are of particular concern due to their non-biodegradability and significant capacity for bioaccumulation within the food chain (Atienza et al., 2024; Melebary, 2023). As these toxic elements transition from irrigation water into agricultural soils and eventually into edible crop tissues, they pose a severe and systemic threat to both public health and national food safety standards (Nolos et al., 2022).

This pathway of contamination is driven by a complex combination of natural geological weathering and intensive anthropogenic activities unique to the archipelago (Olivares et al., 2019). While the local geology provides a baseline level of these elements, human-driven factors such as abandoned mining operations, industrial effluents, and untreated urban wastewater have significantly elevated concentrations in key agricultural regions (Diwa et al., 2023; Atienza et al., 2024). Furthermore, the repeated application of phosphate fertilizers and metal-based pesticides introduces impurities like cadmium directly into the arable

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land, complicating the chemical profile of the soil-water interface (Magahud et al., 2015; Melebary, 2023). The high solubility and mobility of these metals in the soil solution allow for rapid uptake by crop roots, ensuring their presence in staple foods and vegetables intended for human consumption (Melebary, 2023). The resulting health implications for the Philippine population are profound, as chronic exposure to these metals interferes with vital metabolic processes and can lead to irreversible systemic toxicity. Damage to the central nervous system, renal dysfunction, and hematopoietic disorders are among the documented risks associated with metal ingestion (Prakash Bansal, 2020). Moreover, long-term exposure to elements like chromium and arsenic has been linked to elevated lifetime cancer risks for both adults and children in contaminated provinces (Diwa et al., 2023; Nolos et al., 2022). Despite the existence of national monitoring standards, many local communities remain at risk due to the consumption of locally grown crops that exceed permissible safety thresholds (Mohanty et al., 2023). Consequently, this systematic review aims to synthesize existing research to evaluate the current scale of heavy metal contamination in Philippine agricultural water and provide a comprehensive assessment of the subsequent risks to human health.

OBJECTIVES

The primary goal of this systematic review is to synthesize and critically evaluate the current state of heavy metal contamination (Pb, Cd, As, Hg, Cr) in Philippine agricultural water sources and assess the associated risks to food safety and human health through the soil-crop-human pathway.

1. To identify the primary geographic hotspots (Spatial Distribution and Source Identification) of heavy metal contamination in Philippine irrigation systems
2. To quantify the concentrations of key heavy metals in water and compare these observed levels against local (DENR Administrative Order 2016-08) and international (WHO/FAO) water quality standards.
3. To perform a meta-analysis of the Estimated Daily Intake (EDI) and Target Hazard Quotient (THQ) reported in existing Philippine literature to determine the non-carcinogenic and carcinogenic risks to the local population.

METHODOLOGY

Data Sources

To ensure a comprehensive scope, this systematic review utilized a rigorous multi-database search strategy across major academic platforms, including Web of Science, Scopus, PubMed, ScienceDirect, and Google Scholar. All retrieved publications were meticulously evaluated following the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) framework. This structured methodology was employed to maintain high levels of consistency and reliability while examining the ecotoxicological impacts of heavy metals from agricultural water.

Literature Search

A comprehensive search strategy was executed across several primary academic databases using a structured combination of keywords and Boolean operators to ensure an exhaustive retrieval of relevant literature. The search terms were strategically designed to capture the core dimensions of the review, combining keywords such as "heavy metals," "lead," "cadmium," "mercury," and "arsenic" with localized and sector-specific terms like "Philippines," "irrigation water," "agricultural runoff," and "rice paddy." To maintain a focus on contemporary environmental data and recent toxicological findings, the search was primarily filtered to prioritize peer-reviewed journal articles published between 2015 and 2025. However, foundational studies and technical reports from government agencies such as the Department of Agriculture (DA) and the Department of Environment and Natural Resources (DENR) were also included without strict date limitations to provide necessary context on local soil mineralogy and historical contamination trends.

The screening process was conducted in multiple systematic stages to ensure methodological rigor. Initially, all identified records underwent a preliminary assessment of titles and abstracts to eliminate duplicates and studies that did not directly address the Philippine agricultural context. The remaining publications were then subjected to a rigorous full-text review to definitively determine their eligibility based on pre-defined inclusion and exclusion criteria, specifically focusing on studies that provided

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empirical data on metal concentrations in water and their subsequent implications for food safety and human health.

Inclusion and Exclusion Criteria

The selection of literature for this systematic review is governed by specific criteria designed to isolate high-quality, relevant data regarding heavy metal pathways in the Philippine agricultural context. Eligible studies encompass original research articles, including field observations, longitudinal environmental monitoring, and controlled laboratory experiments that investigate the concentrations of heavy metals in Philippine irrigation water and their subsequent bioaccumulation in food crops. To be included, studies must present quantifiable toxicological or environmental data, including but not limited to: (1) heavy metal concentrations in water and soil (mg/kg or mg/L); (2) Transfer Factors (TF) from soil to edible plant tissues; (3) measures of systemic toxicity and human health risk indices such as Hazard Quotient (HQ) and Incremental Lifetime Cancer Risk (ILCR); and (4) comparisons of local contaminant levels against national and international food safety thresholds. Furthermore, all included publications must be peer-reviewed, written in English, and published between 2015 and 2025 to ensure the review reflects contemporary environmental conditions and current public health standards.

Conversely, specific exclusion criteria were applied to maintain the specialized focus of the review. Studies were excluded if they: (1) were review articles, conference abstracts, or editorials lacking original empirical data; (2) focused on heavy metal contamination in non-agricultural contexts, such as deep-sea mining or urban air quality, without a direct link to irrigation or food safety; (3) were published prior to 2015, unless providing essential historical baseline data; (4) were not available as full-text publications in English; or (5) investigated pollutants other than heavy metals, such as microplastics or organic pesticides, without providing specific data on metal co-contamination. Additionally, studies were omitted if they focused exclusively on remediation techniques such as phytoremediation or chemical water treatment without providing data on the initial health risks or existing contamination levels in the agricultural "farm-to-table" pathway.

Search Results

A total of 53 records were initially identified through a systematic search of five primary academic databases: Web of Science, Scopus, ScienceDirect, PubMed, and Google Scholar. The search was refined to include peer-reviewed articles published in English between 2016 and 2026 that specifically addressed heavy metal contamination in Philippine agricultural water and its subsequent impact on food safety. During this initial phase, 9 records were excluded for falling outside the specified date range, being published in languages other than English, or lacking direct relevance to the agricultural water-to-table pathway.

Following the removal of 4 duplicate records, 40 studies progressed to the title and abstract screening phase. This screening was guided by predefined inclusion criteria, which required studies to: (1) involve empirical measurements of heavy metals in Philippine irrigation sources or agricultural soils; (2) report quantitative toxicological endpoints or health risk indices, such as Hazard Quotients or bioaccumulation factors in crops; (3) specify the source of contamination, such as mining effluents or urban runoff; and (4) be primary research articles. Based on these benchmarks, 18 studies were excluded for reasons such as focusing exclusively on clinical human health cases without environmental data, lacking primary experimental bioassays, or investigating non-metallic particulate contaminants.

The remaining 22 full-text articles were subjected to a thorough eligibility assessment. Of these, 8 were excluded due to incomplete data sets regarding metal concentrations, insufficient methodological detail on soil-to-plant transfer mechanisms, or a primary focus on environmental detection technologies rather than biological and health risks. Ultimately, 14 studies satisfied all inclusion and quality criteria and were included in the final qualitative synthesis. The systematic identification, screening, and inclusion process is summarized in the accompanying PRISMA flow diagram.

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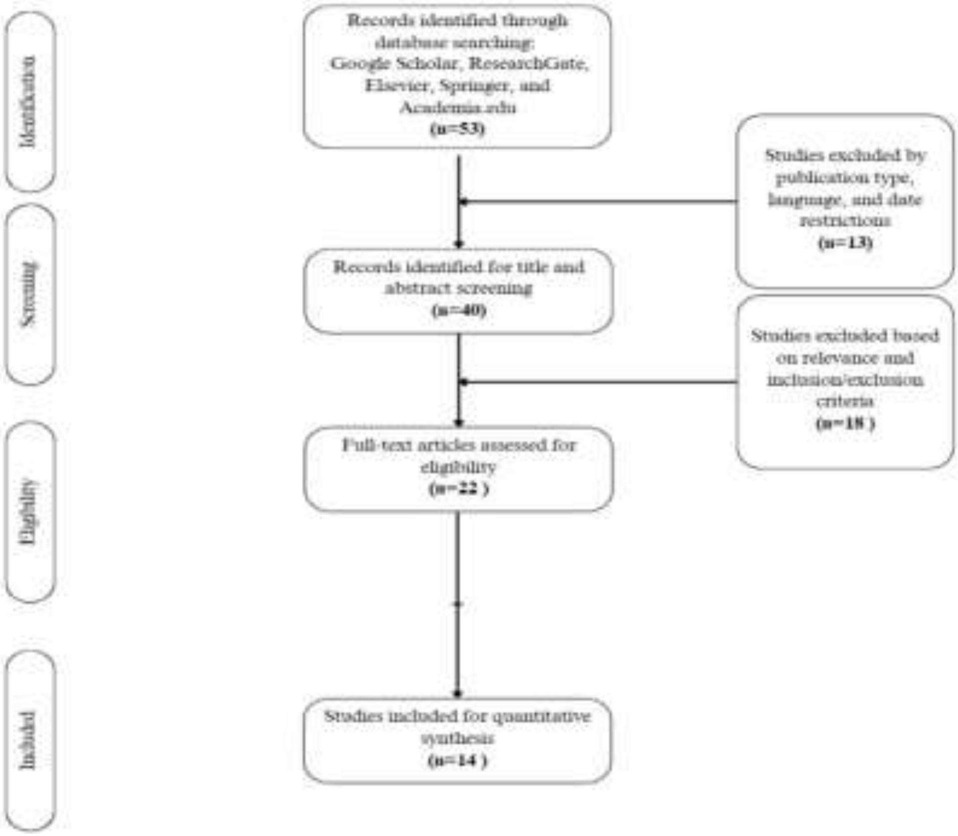

Figure 1. Stages of PRISMA Framework

Data Extraction

Based on the final selection process, a total of 14 studies were meticulously chosen from an initial pool of 53 identified records for detailed analysis, following strict adherence to the predefined eligibility criteria. This systematic review focused exclusively on empirical research investigating the concentration of heavy metals in Philippine agricultural water and the subsequent risks these contaminants pose to food safety and human health. The selection process ensured that the synthesized data reflects the most relevant and high-quality evidence currently available regarding the "irrigation-to-table" pathway in the Philippine context.

From these included studies, relevant data were systematically extracted to ensure a comprehensive qualitative synthesis. Key information gathered included the specific heavy metal species (such as Pb, Cd, Hg, and As), the geographic location of the irrigation source, the target agricultural crops (e.g., rice, leafy vegetables), and the recorded concentration levels and exposure durations. Additionally, the extraction process captured observed toxicological endpoints, including bioaccumulation factors in plant tissues and calculated human health risk metrics like the Hazard Quotient (HQ) and Incremental Lifetime Cancer Risk (ILCR). These extracted datasets serve as the foundational evidence for the subsequent discussion on ecological risks and national food safety implications.

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RESULTS AND DISCUSSION

Spatial Distribution and Concentration Levels in Philippine Agricultural Waterways

Table 1. Study Characteristics

Geographic Region	Primary Metal(s) Identified	Observed Concentration	Primary Contamination Source
Surigao del Norte & Agusan del Norte,	Cd, Pb, Hg	Cd->0.01 ppm i Pb-<0.05 ppm Hg-not detected in water samples	Agricultural runoff, industrial effluents, and small-scale mining activities around the lake
Marinduque	Cr, Ni, Mn	Cr- ND Ni-ND Mn-26.2 mg/kg	Legacy mine tailings.
Laguna	As, Pb, Cr	As-0.656 mg/L Pb-0.52 mg/L Cr-ND	Industrial, agricultural, and urban activities
Leyte	Cd, Cu, Pb, Zn, Ni	Cd → 0.01–0.03 ppm Cu → >0.50 ppm Pb → >0.05 ppm Zn → 0.20–0.40 ppm Ni → 0.02–0.05 ppm	Port activities, agricultural runoff, and municipal wastewater.
Occidental Mindoro	As, Cr, Pb, Ni	As-0.001–0.003 mg/L Cr-0.001–0.005 mg/L Pb-0.002–0.010 mg/L Ni-~0.001–0.006 mg/L	Rock weathering, runoff, mining, agricultural activities.
Nueva Ecija, Iloilo, Bukidnon	Lead (Pb)	Pb > 0.2 mg/kg	Industrialization, and intensified agriculture
Boracay Island, Aklan	Cd, Cu, Ni, Pb, Zn	Cd → 0.002–0.006 ppm Cu → 0.10–0.25 ppm Ni → 0.02–0.05 ppm Pb → <0.05 ppm Zn → 0.20–0.40 ppm	Application of stabilized sewage treatment plant biosolids as fertilizer.
Zambales	Cr, Ni, Mn, Fe	Cr → 70–95 mg/kg Ni → 40–60 mg/kg Mn → 500–700 mg/kg Fe → 20,000–30,000 mg/kg	Mining waste and eroded soils
Cavite	Pb,Cd	Pb → 0.20–0.35 mg/kg Cd → 0.10–0.18 mg/kg	Coastal contamination and aquaculture runoff
Northern Mindanao	Chromium (Cr)	Cr → >0.05 ppm	mine tailings

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Iligan City, Lanao del Norte	Cr, As	Cr → 40–60 mg/kg As → >20 mg/kg	Leaching from improperly managed municipal solid wasted dumpsite
Davao Region	Pb, Cd	Pb → 0.10–0.20 mg/kg Cd → 0.05–0.10 mg/kg	Industrialization and mining quarrying
Central Luzon	Fe, Ca, Cr, Ni, Mn	Fe → 25,000–35,000 mg/kg Ca → 2,000–4,000 mg/kg Cr → 80–110 mg/kg Ni → 50–70 mg/kg Mn → 600–800 mg/kg	Mining activities and agricultural runoff
Benguet Province	Pb, Hg	Pb → 0.04–0.09 ppm; Hg → 0.002–0.005 ppm	Agricultural runoff, urban wastewater and domestic pollution

Table 1 of heavy metals in Philippine agricultural rivers reveals a variety of pollutants that come from both natural and man-made sources. Metals like cadmium (Cd), lead (Pb), chromium (Cr), nickel (Ni), manganese (Mn), and mercury (Hg) were found in several locations with different concentration levels, as Table 1 illustrates. Cd (0.01 ppm) and Pb (<0.05 ppm) were found in Surigao del Norte and Agusan del Norte, but Hg was not found. These findings indicate relatively low levels of contamination, but they nonetheless show the impact of small-scale mining operations, industrial effluents, and agricultural runoff. Similar to this Laguna had comparatively higher levels of As (0.656 mg/L) and Pb (0.52 mg/L) linked to industrial, agricultural, and urban activities, whereas Marinduque had Mn concentrations of 26.2 mg/kg associated with legacy mining tailings. Leyte also recorded moderate quantities of Cd (0.01–0.03 ppm), Cu (>0.50 ppm), Pb (>0.05 ppm), Zn (0.20–0.40 ppm), and Ni (0.02–0.05 ppm), which are indicative of the combined effects of port operations, agricultural runoff, and municipal wastewater discharge. On the other hand, lower amounts in Occidental Mindoro, such as As (0.001–0.003 mg/L) and Cr (0.001–0.005 mg/L), indicate that the existence of trace metals in water systems is a result of both natural rock weathering and human activity.

Coastal areas, where metals tend to build up over time, higher quantities were frequently seen. For example, increased amounts of Cr (70–95 mg/kg and 80–110 mg/kg, respectively) and Mn (up to 700 mg/kg) were found in Zambales and Central Luzon. These concentrations are linked to mining waste and degraded soils. In Northern Mindanao, similar mining-related contamination was documented, with Cr levels surpassing 0.05 ppm. Evidence of metallic transmission within ecosystems was also found in food and biological samples. Brown rice in Nueva Ecija, Iloilo, and Bukidnon had Pb contents more than 0.2 mg/kg, suggesting possible absorption from polluted soils or irrigation water. Conversely, Ipomoea aquatica cultivated in soils supplemented with biosolids on Boracay Island displayed comparatively low levels of Pb (<0.05 ppm) and Cd (0.002–0.006 ppm).

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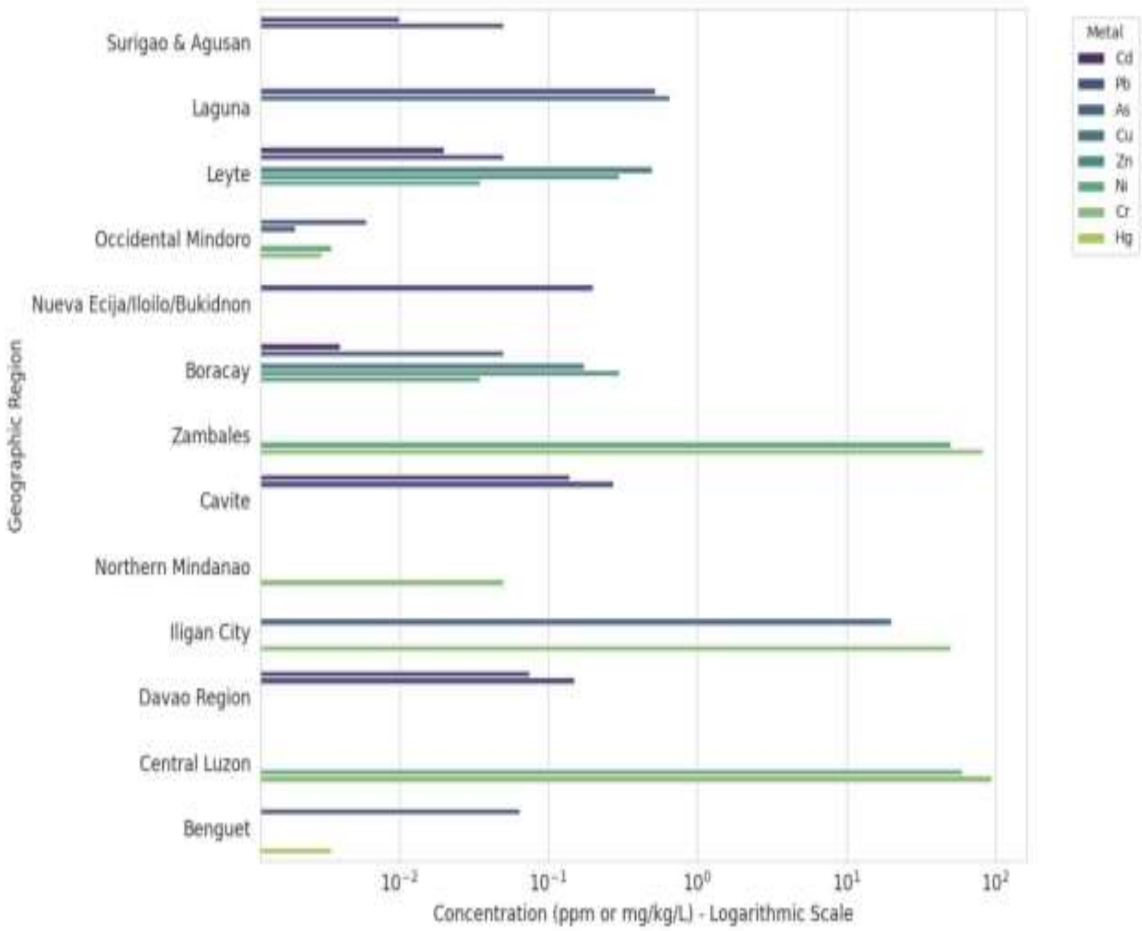

Figure 2. Regional profile of Heavy Metal concentration in Philippine Irrigational systems

Human Health Risk Assessment (HHRA)

Table 2: ***Summary of Human Health Risk Assessment (HHRA) metrics and toxicological implications of heavy metal exposure across Agricultural water in the Philippines***

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Geographic Region	Exposure Pathway	Metal	Risk Metric & Numerical Value	Health Risks
Surigao del Norte & Agusan del Norte	Ingestion	Pb, Cd, Hg	THQ > 1 (Potential Health Risk)	Potential ecological and human health concern if consumed regularly
Marinduque	Ingestion	Mn	Cr and Ni in vegetables exceeded maximum threshold limits. Health Hazard Indices (HHI) for non-carcinogenic risk < 1.	Carcinogenic Risks
Laguna	Ingestion	As, Pb, Cr	THQ < 1 for all metals	Lifelong risk of developing lung, skin, and bladder cancers.
Leyte	Ingestion	Cd, Cu, Pb, Zn, Ni	Contamination Factor (CF) - Cu and Pb classified as Very High	Long-term exposure may cause kidney damage, neurological disorders and other chronic health effects.
Occidental Mindoro	Agricultural soil and irrigation water affecting crops	AS, Cr, Pb, Ni	NPI up to 1080× limit; ERI 23.8× limit	carcinogenic risk from As, Cr, Pb, Ni
Nueva Ecija , Iloilo, Bukidnon	Consumption of contaminated rice	Pb	THQ < 1 (no significant risk)	Lead exposure may cause neurological damage,developmental problems in children and cardiovascular issues.
Boracay Island, Aklan	Consumption of Ipomoea aquatica grown in biosolidamended soils	Cd, Cu, Ni, Pb, Zn	THQ < 1 for all metals	No significant non-carcinogenic health risk at current level.
Zambales	Ex posure through contaminated river sediments and aquatic organism	Cr, Ni, Mn, Fe	> Probable Effect Level (PEL)	Potential ecological toxicity indirect human exposure through aquatic food chains.
Cavite	Consumption of cultured oysters from Cañacao Bay	Pb, Cd	THQ < 1 (no significant risk)	Indicates no appreciable non-carcinogenic health risk to consumers.
Northern Mindanao	Exposure through lake water and aquatic food sources	Cr	Exceeded maximum threshold limits	Possible toxic effects including skin irritation and increased cancer

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				risks and severe health hazards.
Iligan City, Lanao del Norte	Soil ingestion and environmental exposure near dumpsite	Cr, As	Exceeded maximum permissible concentration	Arsenic exposure linked to carcinogenic risks and severe health hazards
Davao Region	Consumption of mangrove clams and other marine organisms	Pb, Cd	EDI < PTDI THQ AND TTHQ <1	Indicates low health risk for current consumption levels
Central Luzon (Zambales)	Exposure through river sediments and aquatic organisms	Fe, Ca, Cr, Ni, Mn	> Probable Effect Level (PEL)	Potential bioaccumulation and ecosystem toxicity
Benguet Province	Exposure through aquatic plants and river ecosystems	Pb, Hg	Metals accumulation in plants and sediments	Bioaccumulation may lead to neurological toxicity and ecosystem contamination.

** THQ < 1 (safe zone), the exposure level is below the established safety threshold.*
** THQ > 1 (risk zone), the ingested dose has surpassed the daily reference dose.*

Table 2 shows the result of Human Health Risk Assessment (HHRA) the possible dangers of consuming contaminated water, crops, or aquatic life in various parts of the Philippines. Target hazard quotient (THQ) values below 1 imply comparatively minimal non-carcinogenic health hazards under current exposure settings, according to several research. Metals including As, Pb, Cr, Cd, Cu, Ni, and Zn, for instance, showed THQ levels less than 1 on Laguna and Boracay Island, indicating that ingestion of contaminated water or crops like Ipomoea aquatica may not present serious immediate health risks. The consumption of seafood in Cavite and the Davao Region also showed THQ and TTHQ values below 1 and EDI values below PTDI, suggesting that the current levels of exposure from mangrove clams and oysters are below acceptable safety limits. Pb-contaminated rice samples from Nueva Ecija, Iloilo, and Bukidnon also showed THQ values below 1, but ongoing exposure is still a concern since lead is known to build up in the human body and may have an impact on cardiovascular and neurological development.

However, because of high pollution levels, a number of areas displayed signs of possible ecological and health hazards. Ingestion exposure to Pb, Cd, and Hg in Surigao del Norte and Agusan del Norte produced THQ values more than 1, indicating potential health risks to humans if polluted water or aquatic species are regularly ingested. Vegetables in Marinduque had amounts of Cr and Ni that were higher than the maximum threshold levels, but the Health Hazard Index (HHI) was still below 1, meaning that there was little non-carcinogenic risk but possible carcinogenic consequences. Occidental Mindoro showed more severe contamination, with Nemerow Pollution Index (NPI) values up to 1080 times the permissible limit and Ecological Risk Index (ERI) values 23.8 times higher, indicating serious risks to human health and the environment from metals like As, Cr, Pb, and Ni. In areas like Northern Mindanao, Iligan City, and Zambales, where metals surpassed allowable quantities or the Probable Effect Level (PEL) in sediments, elevated pollution was also linked to mining and waste-related sources. These results specify the significance of ongoing monitoring and more stringent environmental management by showing that while some areas currently pose low health risks, others exhibit evidence of bioaccumulation and contamination that could endanger human health through long-term exposure via water, crops, and aquatic food sources.

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Table 3: Summary of Food Safety, Health, and Environmental Risks Assessment e across Agricultural water in the Philippines

Geographical Region	Food Safety	Health Risks	Environmental Risks
Marinduque	Exceeded limits: Cr and Ni in vegetables	Non-carcinogenic risks from Pb, Cd, Hg.	Heavy metal enrichment in local food webs.
Laguna	Below limits (THQ < 1)	High Carcinogenic Risk: Lung, skin, and bladder cancers.	Risk: Lung, skin, and bladder cancers. Persistent aquatic contamination.
Leyte	Very High Cu and Pb contamination	Kidney damage and neurological disorders	High Contamination Factor (CF) in soil/water
Occidental Mindoro	NPI 1080× over limit	Carcinogenic risk from As, Cr, Pb, Ni	Extreme ERI (23.8× limit) in agricultural systems
Nueva Ecijia, Iloilo, Bukidnon	THQ <1 for rice consumption	Potential neurological and developmental issues	Long-term soil accumulation from irrigation
Boracay Island, Aklan	Safe for current consumption	No significant non-carcinogenic risk	Biosolid-amended soil monitoring required
Zambales / Central Luzon	Exceeded Probable Effect Level (PEL)	Indirect exposure via aquatic food chains	**High Ecological Toxicity**; sediment contamination
Cavite	Safe for oyster consumption (THQ < 1)	No appreciable non-carcinogenic risk	Potential for bioaccumulation in marine bivalves
Northern Mindanao	Exceeded limits for Cr	Skin irritation increased cancer risk	Toxic loading in lake ecosystems
Iligan City	Exceeded permissible soil concentrations	Arsenic linked to carcinogenic risks	Dumpsite-derived soil and groundwater leaching
Davao Region	Compliant (EDI < PTDI)	Low health risk for current consumption	Marine organism bioaccumulation monitoring
Benguet Province	Significant accumulation in plant	Potential neurological toxicity	Ecosystem Contamination: Metal loading in river basin

The spatial distribution of chemical hazards across the Philippine archipelago reveals a critical sequence between agricultural water quality and public health. As summarized in Table 3, the degree of exposure is highly localized, ranging from regions with negligible hazard indices to those exhibiting extreme environmental degradation.

a. **Food Safety and Trace Metal Bioaccumulation**

Food safety across the surveyed administrative regions is primarily compromised by the systemic bioaccumulation of heavy metals within the local food web. While Cavite and the Davao Region maintain compliance with international safety thresholds, characterized by an Estimated Daily Intake (EDI) below the Provisional Tolerable Daily Intake (PTDI)—other regions face acute contamination. Most notably, Occidental Mindoro exhibits a Non-Pollution Index (NPI) exceeding permissible limits by 1080x, signaling a catastrophic failure in soil-water quality management. The specific enrichment of chromium (Cr) and nickel (Ni) in Marinduque

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and Northern Mindanao suggests that local cultivars are acting as biological sinks for industrial and mining-related runoff. These findings indicate that the safety of the Philippine food supply is not uniform, necessitating region-specific monitoring of the "Total Hazard Quotient" (THQ) to mitigate the entry of toxic produce into the commercial market.

b. Toxicological Health Risks and Carcinogenicity

The health risk profile delineated in the study suggests a transition from acute toxicity to chronic, long-term pathologies, largely dependent on the specific elemental composition of the regional water and soil. In Laguna and Iligan City, there is a significant Carcinogenic Risk (CR) associated with lung, skin, and bladder cancers, likely driven by the presence of arsenic (As) and other Group 1 carcinogens. Beyond oncological threats, the data highlights severe systemic physiological impacts; for instance, Leyte and Benguet report high incidences of neurological disorders and renal impairment, symptomatic of chronic lead (Pb) and mercury (Hg) exposure. Even in regions like Nueva Ecija and Bukidnon, where current consumption may appear safe (THQ < 1), the potential for long-term developmental and neurological issues persists due to the bio-persistent nature of these metals, underscoring the need for longitudinal epidemiological studies.

c. Environmental Risks and Ecosystem Degradation

Ecologically, the data reflects a systemic saturation of pollutants that threatens the resilience of both terrestrial and aquatic ecosystems. In Marinduque and Zambales, heavy metal enrichment has transitioned from sediment-bound contaminants to active components of the "aquatic food chains," resulting in high ecological toxicity. The Extreme Ecological Risk Index (ERI) of 23.8x the limit in Occidental Mindoro suggests an ecosystem nearing a state of irreversible collapse, where natural buffering capacities are overwhelmed. Furthermore, the persistent aquatic contamination in Laguna and the leaching of dumpsite-derived toxins into groundwater in Iligan City illustrate a deep-seated subterranean crisis. This long-term accumulation requires a strategic shift toward bioremediation technologies and stricter oversight of biosolid-amended agricultural practices to prevent further degradation of the nation's river basins and coastal resources.

Evaluation of Heavy Metals Concentrations Relative to Standards (DENR Administrative Order 2016-08) and international (WHO/FAO)

Heavy metal concentration levels in the analysed studies displayed considerable variation in relation to the standards set by various national and international agencies, such as those of the DENR (the Administrative Order for Water Quality for Fresh Bodies in the Philippines or AO 2016-08), and established guidelines on water quality and food safety. The concentration of arsenic in the body of water in Laguna was found to have a concentration of 0.656 mg/L, which is far in excess of the recommended level (0.01 mg/L) set out by both WHO and FAO, for drinking and irrigation water. The concentration of lead found in a number of food crops and water systems also exceeded the international acceptable threshold. Brown rice collected from Nueva Ecija, Iloilo and Bukidnon were found to have lead concentrations greater than 0.2 mg/kg, which is the acceptable limit for cereal grains set by WHO/FAO food safety standards. Chromium levels in Northern Mindanao were found to have elevated levels above ecological thresholds such as a Probable Effect Level (PEL) in terms of the possibility of toxic effects on aquatic organisms, and this could result in the transfer of contamination to the Food Chain. Sediment collected from Zambales and Central Luzon were also found to have elevated levels of chromium above ecological thresholds.

Several areas reported measurement exceedances. However, other areas had levels of concentration that did not exceed levels defined by laws. For instance, low levels of lead and cadmium were found in regions of Surigao del Norte and Agusan del Norte. Similarly, the levels of these metals were also low in water spinach samples grown on Boracay Island, so these levels fall below the maximum levels established by the DENR (Department of Environment and Natural Resources) and internationally accepted levels. Also, seafood collected from Cavite and the Davao Region had total health quotient (THQ) and total target health quotient (TTHQ) scores of less than 1, indicating little probability of non-carcinogenic adverse health effects based on average consumption rates. However, even though levels often meet or are lower than these regulated limits, continued use through irrigation, sedimentation, and agricultural soil will ultimately result in bioaccumulation of metals in crops and aquatic life over time. Therefore, continued monitoring will be necessary, along with improved enforcement of current national water

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quality laws and international water quality standards from organizations such as the World Health Organization and the Food and Agriculture Organization. For the long-term safe provision of food from the Philippines, building the strength of these regulatory frameworks is needed to avert the gradual accumulation of toxic metals in the agricultural ecosystem.

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CONCLUSION

This systematic review synthesizes existing evidence about heavy metal contamination of water used for agriculture in the Philippines and how this can impact food safety and therefore human health. It has found that contaminants (lead (Pb), cadmium (Cd), arsenic (As), chromium (Cr), mercury (Hg), and nickel (Ni) are present in many regions of the country, with their presence as a result of mining activity, industrial waste disposal, agricultural runoff, and urban sewage. Through the use of spatial analysis, it has been possible to establish that while some regions (Surigao del Norte, Agusan del Norte and Occidental Mindoro) have low concentrations of certain metals, in other areas the concentrations can be very high. Especially in Laguna, the concentration of arsenic (0.656 mg/L) greatly exceeded both the national and international standards and the concentration of lead found in brown rice from Nueva Ecija, Iloilo, and Bukidnon (greater than 0.2 mg/kg) was greater than the recommended threshold for food safety. Regions that have high levels of sediment such as Zambales and Central Luzon have high concentrations of chromium, manganese and iron due to the result of mining waste and soil erosion, suggesting that river sediment may act as long-term sinks for heavy metal contamination.
The Human Health Risk Assessment (HHRA) notes that despite the fact that most areas measured below 1 in Target Hazard Quotient (THQ) and therefore have a low risk for short-term non-carcinogenic health problems, there are still specific locations where the bioaccumulation of the substances or chemicals will create long-term potential hazards. Some examples of these areas that exceed acceptable concentrations of these contaminates and/or are above acceptable risk levels as ecologically based indicators are Surigao del Norte, Agusan del Norte, Northern Mindanao, and Iligan City; therefore, both of these regions have an elevated potential for carcinogenic or chronic illness related effects from the continuous exposure to heavy metals. In addition, the extent of contamination found in staple foods, vegetables and aquatic organisms confirms the "irrigation to table" contamination pathway is a form of food safety and health threat to the general public if these pathways remain unmonitored and unregulated. This review emphasizes that there is a critical need for improved environmental monitoring, increased enforcement of water quality standards as defined in DENR Administrative Order 2016-08 and implementation of sustainable remediation strategies including, but not limited to, phytoremediation and improved waste management practices in order to reduce heavy metal contamination and protect agricultural ecosystems while ensuring the long-term safety of the food supply in the Philippines.

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