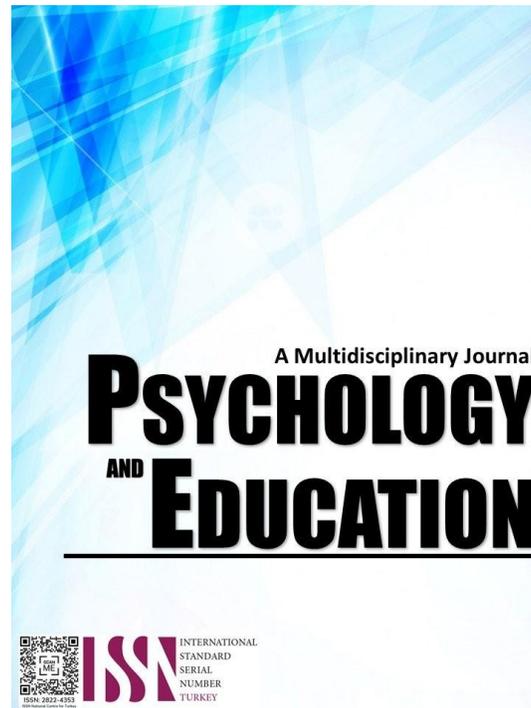


**A SYSTEMATIC REVIEW AND META-ANALYSIS ON THE STATUS OF
HEAVY METALS IN BODIES OF WATER IN THE PHILIPPINES:
POLICY BRIEF DEVELOPMENT FOR LOCAL
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A Systematic Review and Meta-Analysis on the Status of Heavy Metals in Bodies of Water in the Philippines: Policy Brief Development for Local Government Units

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Abstract

Heavy metals can come from both natural and anthropogenic sources. These substances are non-biodegradable and bioaccumulative. With this, their presence in the environment poses both non-carcinogenic and carcinogenic health risks to surrounding communities, as these substances can enter the body through the oral or dermal routes of exposure. This study determined whether the hazard quotients calculated from actual lead and cadmium concentrations exceed those calculated from DENR standards. Following this, a policy brief was drafted based on the findings of the study. This study was conducted through a systematic review and meta-analysis of published studies from various research databases. The conducted meta-analysis indicates overall effect sizes of 9.29 for cadmium and 3.20 for lead, suggesting an excess of allowable heavy metal concentrations in the identified bodies of water in the Philippines. It was also determined through human health risk assessment calculations that the majority of hazard quotients and incremental lifetime cancer risk values have exceeded accepted standards, indicating possible harm to surrounding communities. Finally, the formulated policy brief focuses on community participation and engagement, improvements to waste treatment facilities, the implementation of advanced monitoring systems, and the formulation of improved programs to enhance the management of heavy metals in the environment.

Keywords: *cadmium, lead, policy making, hazard quotient, human health risk assessment, DAO 2016-08, Philippines*

Introduction

Heavy metals are identified as metals with an atomic number greater than 20 and a specific gravity at least five times that of water (e.g., lead, cadmium, and copper) (Raychaudhuri et al., 2021). These substances are naturally occurring throughout the earth's crust, but most heavy metals in the environment come from effluents from anthropogenic activities, such as industrial, agricultural, and domestic sources (Tchounwou et al., 2012; He et al., 2005).

Upon entering the environment, these substances tend to bioaccumulate, both in the environment and within living organisms, due to their non-biodegradable nature (Yadav et al., 2019). Although a certain amount is beneficial to living organisms, such as in human metabolism and in maintaining certain processes in plants, excessive amounts are toxic when taken in, causing adverse effects (Kiran & Sharma, 2021). The usual route of exposure of heavy metals from their sources to living organisms begins in industry. This is then discharged into the environment through the atmosphere, water, or soil, and can be taken in by humans and animals via oral, nasal, or dermal absorption (Azeh Engwa et al., 2019).

When accumulated, this poses a problem for various communities, as they depend on accessible, available, and affordable water for their day-to-day activities. This situation is not much different in the Philippines, where the progress and development of communities are heavily reliant on clean water (Senate Economic and Planning Office, 2011). However, there have been many recent reports that various bodies of water in the Philippines are not only highly polluted but also among the world's top ocean polluters (Mayuga, 2021; UNEP, 2017; McCarthy, 2016).

Due to heavy pollution, lack of funding, and irresponsible water resource management, the country has experienced water stress since 2017, meaning that the scarcity of clean, accessible water has been a longstanding problem (Lapong & Fujihara, 2008; SEPO, 2023; Gorme et al., 2010). The availability and accessibility of freshwater significantly affect the direction of a community's socio-economic development (Zhou et al., 2017). Third-world countries such as the Philippines are severely affected by water scarcity. Most illnesses, food security, a community's mortality rate, and even the advancement of gender equality are heavily dependent on a country's access to potable water (Starkey, 2012; Government of Canada, 2024).

In response to the country's water crisis, the government implemented the Philippine Clean Water Act of 2004, or Republic Act 9275 (Malenab et al., 2016). This aims to "protect the country's water bodies from pollution from land-based sources. It also provides a comprehensive and integrated strategy to prevent and minimize pollution through a multi-sectoral and participatory approach involving all stakeholders" (DENR-EMB, 2024). Apart from this, other bills were proposed, local and national government institutions created, and laws passed to address challenges in water management (Lapong & Fujihara, 2009; Alikpala & Ilagan, 2018; SEPO, 2023).

However, despite efforts to implement the aforementioned responses, the problem lies in the various challenges the country faces in water management. An identified challenge is insufficient funding. This results in the weakened implementation of formulated strategies, a lack of updated research, and a lack of the necessary infrastructure for water treatment (Gorme et al., 2010). In addition, a lack of coordination among the established government agencies responsible for water-related issues and a lack of capacity-building for local government units (SEPO, 2023). Lastly, to date, there has been no specific response that focuses on the regulation and

management of heavy metals in bodies of water. For this study, only studies that test for the concentrations of both cadmium and lead in Class C bodies of water are considered, as these are the most common heavy metals tested in available studies on bodies of water in the Philippines.

Therefore, a systematic review and meta-analysis of the current status of cadmium and lead in bodies of water in the country is deemed essential to formulate policies for the regulation and management of these substances, thereby improving water quality and, consequently, public health. Through this study, the prevalence of adverse health risks may be identified among communities heavily dependent on these bodies of water. Apart from this, informed policies can be drafted that enable community members to practice sustainable processes and responsible water resource management.

The results from this study will be shared in various relevant research forums. Following this, the study will be subject to online refereed journal publication. Lastly, the proposed policy brief will be shared with Local Government Units (LGUs) to formulate the appropriate policies contextualized to their respective areas of responsibility.

Research Questions

This study aimed to examine the current status of heavy metal contamination in Class C bodies of water in the Philippines. Specifically, it sought to answer the following questions:

1. Does a heavy metal assessment of Philippine bodies of water demonstrate variations in calculated hazard quotients (HQs) based on actual heavy metal concentrations and DENR standards?
2. Based on the findings of this systematic review and meta-analysis, what policy brief can be drafted?

Methodology

Research Design

This study employed a systematic review and meta-analysis design to assess the overall status of the heavy metals lead and cadmium in selected bodies of water in the Philippines. The use of this tool aimed to synthesize the results of selected studies with similar objectives to provide a comprehensive conclusion.

A systematic review is anchored in a well-defined research question, followed by a critical selection of studies to extract and analyze data for inclusion in the review (Armstrong et al., 2008). This is also defined as a summary of several literature that uses scientific strategies that begin with compiling various pieces of literature, systematically assembling these through methods of analysis, evaluation, and synthesis, and proceeding with reporting evidence collected that would allow the formation of a relevant conclusion relevant to what the information is that is being sought (Denyer & Tranfield, 2009).

A systematic review begins with the objectives and questions that define the overarching goal of the study. A thorough selection of published and unpublished studies would then be sorted based on inclusion and exclusion criteria that would be stated in the protocol. The studies are then evaluated for quality and validity, and, once again, rechecked to determine whether they are fit to be included in the study. The included studies would then be analyzed, conclusions drawn, and findings reported, along with the methodology used for the study (Aromataris & Pearson, 2014). A thorough review of the studies by a qualified expert is necessary because, if the studies considered are sufficiently similar, a meta-analysis would be deemed necessary to form better conclusions for the objectives of the study (Wright et al., 2007).

A meta-analysis is a statistical strategy that aims to summarize the results of multiple studies in a systematic review (Borenstein et al., 2021). With the exponential growth of literature in education and the conflicting solutions and conclusions to the same research questions, meta-analysis is believed to be the most viable means of synthesizing and drawing general conclusions from the available literature (Van Wely, 2014). Apart from this, findings from meta-analyses are said to have numerous advantages, such as higher accuracy and credibility, as opposed to other methods of research or to systematic reviews that are not followed by a meta-analysis (Rosenthal & DiMatteo, 2001).

Meta-analysis of observational studies is applicable for answering questions for which randomized evidence is insufficient or unavailable (Metelli & Chaimani, 2020). In this study, a meta-analysis of the collected studies is deemed necessary to provide data on the current levels of heavy metals in the country and their potential risk to human health.

Respondents

This systematic review follows the “Cochrane and Preferred Reporting Items for Systematic Review and Meta-Analysis (PRISMA)” guidelines for screening related studies. Furthermore, as the study progressed, the PRISMA 2020 Checklist was followed to ensure compliance with all necessary components of the study.

All studies describing the presence of heavy metals in bodies of water in the Philippines, along with their associated health hazards, were sought in various online databases, including Google Scholar, ResearchGate, Base, EBSCO, SEAFDEQ/AQD, and PubMed, from 1990 to March 2024. The keywords used were ‘heavy metal’ OR ‘heavy metals’ AND ‘bodies of water’ OR ‘surface water’ OR

'river' OR 'lake' OR 'ocean' OR 'marine water' OR 'freshwater' AND 'Philippines' OR 'Republic of the Philippines'.

Instrument

Quality assessment in systematic reviews is a necessary step for ensuring the quality of the studies included in the review. The use of standardized tools for quality assessment helps evaluate the validity of the included studies (Negarandeh & Beykmirza, 2020). The use of such tools in quality assessment enables better analysis of the strength of the evidence and the biases embedded in the studies (HSLIB, 2024). Not only this, with the many available studies in various online databases, ensuring their quality increases their credibility and reliability, especially regarding the data that they provide. Collectively, the studies included in the systematic review would produce high-quality, unbiased results, yielding conclusions that can help make better data-driven decisions (Ebrahimi, 2024). For the systematic review of this study, two (2) colleagues assisted in validating the quality of the included studies using the STROBE checklist.

Strengthening the Reporting of Observational Studies in Epidemiology (STROBE). Considering that the studies collected already contain the necessary data for the meta-analysis and that no further manipulation will be done, these studies are considered observational in nature (Indeed Editorial Team, 2023). As such, Lang and Kleijnen (2010) deemed it necessary to develop consensus on criteria for checklist creation to quantify the quality of observational research studies. As a result, it has become a trend for those conducting systematic reviews and meta-analyses to use the STROBE checklist as one of the most frequently cited tools for quality assessment of observational studies.

The STROBE (Strengthening the Reporting of Observational Studies in Epidemiology) Checklist aims to address the "incomplete and inadequate reporting of research" in studies that are being reported. This is essentially a 22-item checklist of items to include in articles reporting observational studies (STROBE, 2024). Therefore, for this systematic review and meta-analysis, the quality of the studies was assessed based on the STROBE checklist.

Procedure

Data extraction involves sifting through and separating the relevant information from the studies to be included in the review. The organization of this information serves to integrate the studies' findings and draw conclusions (UH: Health Sciences Library, 2022).

In this review, all eligible studies were systematically organized and analyzed according to the inclusion criteria. These were then tabulated with the use of Microsoft Excel (MS Excel) to organize the statistical details relevant to the review, which included, but were not limited to, the following: title, author, date of publication, location of the body of water, sampling method used (when available), amount and type of heavy metal/s available. After this, the data were processed using statistical software. In this case, Jamovi was utilized for the meta-analysis.

Data Analysis

The meta-analysis phase of this study was adapted from the study of Ravanipour et al. (2021). The data's means, standard deviations, effect sizes (e.g., SMDs and their standard errors), Q-test, I-square test, tau-squared, forest plot analysis, and funnel plot analysis were used to synthesize the quantitative findings from the various qualified research studies.

Meta-analysis is typically a two-stage process. The first stage in the process considers a summary statistic. This is calculated for each study, which describes the observed intervention effect.

Data from the systematic review were used to conduct a human health risk assessment to identify and understand the hazards posed by heavy metals in bodies of water to society. The data collected from such an assessment were vital for formulating the policy brief.

Descriptive Statistics. From the raw data collected, the descriptive statistics used were the mean and standard deviation. The pooled mean and standard deviation from the included studies were also computed, as these were used to calculate Cohen's D, which provided the data for the Standardized Mean Difference effect size. From this, the standard error of the effect size was calculated, using the study's mean as n_1 and the accepted value of the heavy metal from the DAO 2016-08 of the included studies as n_2 . Both the effect size and its standard error are required to conduct the meta-analysis for the study.

Heterogeneity (Q and I-square Tests). Both the I² index and Cochran's Q test are tests for heterogeneity. However, both also serve different purposes than just testing for heterogeneity. Cochran's Q test is the usual test for assessing true heterogeneity. Through this test, we would be able to determine whether the meta-analysis should proceed as a fixed- or random-effects model, with the rejection of homogeneity leading to the latter. The I² index, on the other hand, not only assesses heterogeneity but also determines its extent as low, medium, or high (West et al., 2010).

Forest Plots. Forest plots were included in the presentation of the meta-analysis results, as they display multiple variables in a single plot (Hartman, 2023). Specifically, this provided a visual representation of the heterogeneity of the studies involved and the estimated common effect (Fagerland, 2015). This visual representation is important because it allows for easier observation of variations across the studies included in the systematic review (Li et al. 2020).

Random Effects Model. In the study, the Random Effects Model (REM) was used as the studies have a low chance of being functionally

identical (done the same way by the same set of researchers). This was used to consider the presence of uncertainty which results from the heterogeneity of the studies that passed the inclusion criteria (Borenstein et al. 2009).

Funnel Plot and Publication Bias. Since published studies are more likely to find their way into a meta-analysis, any bias in the literature is likely to be reflected in the meta-analysis as well. To check for publication bias, the following tests can be performed according to Borenstein et al. (2009): Egger's test and Rosenthal's Fail-Safe N Method. To begin with, a funnel plot was created. This is a simple scatter plot of the intervention effect estimates from individual studies against the calculated standard error.

To test for the plot's asymmetry, Egger's test was done. This identifies a straight-line relationship between the standardized mean difference effect size and standard error. The greater the association between intervention effect and standard error, the more the slope would move away from vertical.

To address publication bias, Rosenthal's Fail Safe N method was used. This test considers the number of studies required in order to present the overall treatment effect as nonsignificant. Essentially, the results of this test helped assess the robustness of the meta-analysis, indicating whether it would be easily overturned by the addition of a few studies.

Hazard Quotient. This assessment is done to determine the probability of harm to people from their exposure to heavy metal contaminants in bodies of water in their areas (DEC SOA, 2024). Ingestion and dermal transmission are the most common means of transmission of heavy metals to humans (Tchounwou et al, 2012). As heavy metals are known carcinogens, both the carcinogenic and non-carcinogenic risks posed by heavy metals via dermal absorption and ingestion were considered, using the methods followed by Bilal et al. (2023) and Parvin et al. (2022).

The calculations for the average daily intake dose (ADI) were estimated as follows for each route of exposure, as adapted from Mariano (2019) and Duggal et al (2017):

$$ADI_{\text{ingestion}} = (C \times HM \times IR \times EF \times ED) / (BW \times AT)$$

$$ADI_{\text{dermal}} = (C \times HM \times AF \times SA \times ABSHM \times EF \times ED \times CF) / (BW \times AT)$$

Where ADI is measured in mg/kg/day. $ADI_{\text{ingestion}}$ is the daily intake dose of a specific heavy metal through ingestion while ADI_{dermal} is for dermal contact with the identified substrate particles; CHM is the average concentration of the identified heavy metal in water and is measured in mg/L; IR is the water intake rate in L/day (2.5 for adults, 0.78 for children); EF is the frequency of exposure in days (350 for both adults and children); ED is the duration of the exposure in years (26 for adults, 6 for children); BW is body weight (approximated at 80 kg for adults and 15kg for children); and AT is the average time for non-carcinogens in days (25500 for both adults and children). For the second equation, SA is the exposed skin area in cm² (19652 for adults, 6365 for children), AF is the skin adherence factor in mg/cm² (0.07 for adults; 0.2 for children); ABSHM is the dermal absorption fraction of the heavy metal (0.1); and CF is the conversion factor (1×10^{-6}).

The Hazard Quotient (HQ) was also used to estimate the non-carcinogenic effects of heavy metals from human exposure and drinking. This is merely the ratio between the estimated daily intake and the reference risk dose (Rfd) presented mathematically as follows:

$$HQ = ADI / Rfd$$

Ethical Considerations

The proponent applied to the University of the Immaculate Conception - Research Ethics Committee (UIC-REC) for an exemption for the protocol to be used in this study. The study did not involve human participants or identifiable human tissue, biological samples, and data. Furthermore, there was no risk of harm because the research and the information collected is already in the public domain. Also, secondary data sets remained non-identifiable during access, use, and dissemination.

Results and Discussion

This section presents the findings, analysis, and interpretation of the collected data, which aim to answer the study's review question. The order of presentation in this discussion is as follows: Study Selection, Features of the Included Studies, Study Locations, PICO Framework, and the Meta-analysis of the collected data.

Study Selection

Studies were primarily collected using the selected keywords presented in the Data Sources and Selection section of the previous chapter. 86 studies were collected from various online databases. 16 duplicates obtained from different databases were then removed from the selection. The 70 studies were then initially screened, wherein 12 journals were deemed irrelevant because of their title, abstract, and keywords; 2 journals were discarded from the list because the full text was not accessible; and, upon further inspection of the publicly available journals, 9 were removed because no actual testing of heavy metals was done in the study. The inclusion and exclusion criteria were then applied to determine the eligibility of the remaining 47 studies. From these, 24 studies were excluded due to incomplete data, 11 were removed because the bodies of water were not classified as Class C under DAO 2016-08, 3 were reviews, 2 were not peer-reviewed, and 1 was from a conference presentation. 6 studies that met the inclusion criteria were included in the



systematic review and meta-analysis.

Table 1. Features of the Included Studies

Study No.	Title of Study	Author/s (year)	Location	URL	Study Design
1	Biomonitoring of Water Bodies in Metro Manila, Philippines Using Heavy Metal Analysis and Erythrocyte Micronucleus Assay in Nile Tilapia (<i>Oreochromis niloticus</i>)	Alam et al. (2019)	Estero de Paco & Estero de Vitas, Tondo, Manila (Class C)	https://neptjournal.com/upload-images/NL-69-3-(1)-D-884.pdf	Cross-sectional
2	Assessing heavy metals in the waters, fish and macroinvertebrates in Manila bay, Philippines	Su et al. (2009)	Las Piñas-Parañaque Lagoon Manila Bay, Manila (Class C)	https://www.researchgate.net/publication/44024637_Assessing_heavy_metals_in_the_waters_fish_and_macroinvertebrates_in_Manila_bay_Philippines	Cross-sectional
3	Water Quality and Removal Efficiency of Suspended Solids, Copper, Lead, and Oil/Grease in Malihao River, Negros Occidental, Philippines using Bivalve Shells	Morata et al. (2019)	Malihao River, Victorias City, Negros Occidental, Philippines (Class C)	https://www.researchgate.net/publication/339293276_Water_Quality_and_Removal_Efficiency_of_Suspended_Solids_Copper_Lead_and_OilGrease_in_Malihao_River_Negros_Occidental_Philippines_Using_Bivalve_Shells	Cross-sectional
4	River flow pattern and heavy metals concentrations in Pasig River, Philippines as affected by varying seasons and astronomical tides	Paronda et al. (2019)	Pasig River, Manila (Class C)	https://www.researchgate.net/publication/336966727_River_flow_pattern_and_heavy_metals_concentrations_in_Pasig_River_Philippines_as_affected_by_varying_seasons_and_astronomical_tides	Cross-sectional/ Longitudinal
5	Water Quality Assessment of Antiao River in Samar, Philippines	Amasual et al. (2024)	Antiao River, Samar (Class C)	https://www.researchgate.net/publication/380074722_Water_Quality_Assessment_of_Antiao_River_in_Samar	Cross-sectional
6	Heavy metals in surface waters of Laguna de Bay, Philippines: current levels and trends	Sacdal et al. (2021)	Laguna de Bay (Class C)	https://www.researchgate.net/publication/353645595_Heavy_metals_in_surface_waters_of_Laguna_de_Bay_Philippines_current_levels_and_trends	Cross-sectional/ Longitudinal

Table 1 provides the relevant features of the selected studies in the meta-analysis. The 6 selected studies were conducted from 2009 to 2024. The gathered data were from online research journal databases published and generated by various authors across the Philippines. The studies were conducted on various bodies of water across the Philippines, classified under DENR Administrative Order (DAO) 2016-08 according to their use as fresh or marine waters. Among the studies collected, four are from Luzon, while 2 are from Visayas. The majority of the studies also use a cross-sectional design, with two using a mix of cross-sectional and longitudinal designs.

Three (3) of the four (4) studies done in Luzon are from Metro Manila and one (1) study is from Laguna Lake, Laguna.

In Metro Manila, one (1) study was done on Manila Bay, one (1) in Tondo, and the other along the Pasig River. Metro Manila, also known as the National Capital Region (NCR), is called the “country’s political, economic, and educational center” (DTI, 2024). It has a land area of 636 km² and a population of close to 15 million (Balita, 2023; Macrotrends, 2024), making this the smallest and most populated city in the Philippines. According to WEPA (2019), there is a strong correlation between the deterioration of bodies of water in the vicinity of densely populated urban areas and the rapid increase in population and industrialization in those areas. In Metro Manila, domestic waste contributes to 65-70% of water pollution. The remaining percentage comes from factories, industries, and poor solid waste management disposal practices (Ranada, 2014).

In addition, located in Luzon is the largest body of freshwater in the country. The Laguna Lake (also known as Laguna de Bay) covers an area of 900 km² and is estimated to hold 2.25 billion m³ of water (Global Nature Fund, 2024). The Laguna Lake Development Authority (LLDA) (2024) calls Laguna Lake a “multi-use water resource” as the lake caters to varied anthropogenic activities for a population of almost 15 million people. Some of these are as follows: fisheries, flood reservoirs, power generation, recreation, irrigation, industrial cooling, waste sinks, and as a source of potable water. The establishment of the LLDA supports both CBNRM theory and the political decentralization and fit theory, which argue that community-based actions can better address community issues by providing context-specific solutions. According to Agrawal and Ribot (1999), democratic accountability is a pathway to improving the conditions of natural resources and to better managing the benefits derived from them.



In the study by Lin et al. (2022), water pollution is mainly man-made, with the industry sector identified as the leading cause. Chen et al. (2019) also state that the industrial sector significantly contributes to the pollution of harmful chemicals, including heavy metals, in various bodies of water.

Laguna Lake is connected to Manila Bay through the Pasig River. According to Alam et al. (2019), 47 estuaries drain into the Pasig River, most of which are heavily polluted due to anthropogenic activities in surrounding communities and industries. With a total length of 27 km, the river passes through six municipalities and is notorious for being the “world’s most polluted river” (Paronda et al 2019). A 2010 study by Gorme et al. found that rapid population growth, urbanization, and industrialization are the main reasons for the death of the Pasig River. There has been a concerning trend of increased anthropogenic waste deposition. This is likely attributable to domestic sources from informal settlements established along the riverbanks and its tributaries, and industrial sources from surrounding commercial establishments.

Two (2) studies were conducted in Visayas. One (1) study was conducted in Samar, and one (1) in Negros Occidental. The studies conducted in Visayas were on rivers. Specifically, the Antiao River in Samar and the Malihao River in Negros Occidental.

Rivers are critical freshwater ecosystems whose survival and sustainability depend on a delicate balance of several internal and external factors. These bodies of water can support the sustainability of their environments. However, it also needs constant attention through proper maintenance and remediation activities (Jordaan, 2024). A common theme across the studies is that anthropogenic uses of river systems are the main drivers of their degradation. Common activities in the studied river systems include unregulated industrialization leading to river pollution, degradation due to deforestation, and rapid population growth (Morata et al., 2019; Guino-o et al., 2015). Among these, river pollution due to the surrounding industries has the greatest capacity to disrupt the natural flow of the ecosystem and the equilibrium between the environment and its inhabitants. The heavy dependence of surrounding communities on river systems is supported by the poverty and environmental resource degradation theories. The absence of the concept of sustainability and the immediate need to address short-term needs lead to the degradation of nearby natural resources.

Five of the six studies included are available on ResearchGate. This is a well-known research database that connects over 25 million researchers in 190 countries, enabling them to connect, collaborate, and share their work. Apart from the diverse collection of multidisciplinary journals available in the database, researchers can also interact and share their knowledge on the website. The links to the 5 studies all have available full-text journal articles on ResearchGate. One study was found in the Nature Environment and Pollution Technology Journal through a search on Google Scholar. This is a reputable open-access online journal with a rigorous peer-review process prior to publication of studies.

Four of the six studies included have a cross-sectional study design. Cross-sectional studies are a type of observational study design in which researchers measure the outcome, specifically the desired data (e.g., heavy metal concentration), while considering the exposure of the point of interest at a specific point in time. These types of studies provide data on outcomes or exposures and are thus useful for policy-making, monitoring, and evaluation (Setia, 2016). Two studies use a longitudinal study design. This is also an observational study design. However, sampling and the collection of data are done multiple times over an extended period of time. With multiple data points, developments and changes in the point of interest may be observed and detected (At Work, 2015).

Population, Intervention, Comparator, and Outcome (PICO) Framework

The Population, Intervention, Comparator, and Outcome (PICO) framework components work together to answer the study's research question (UC Library, 2023). A clear and well-directed research question helps guide the study, including the necessary parts of the systematic review and meta-analysis such as the inclusion and exclusion criteria, the search strategy, and the data collection (RMIT University, 2024).

Tables 2 and 3 show the four components of the PICO analysis of the 6 studies included in the systematic review and meta-analysis. Table 2 considers dermal exposure to heavy metals, while Table 3 considers oral exposure.

Table 2. Point of Interest, Intervention, Comparator, and Outcome (PICO) Components of Studies (Dermal)

ID	Title	Point of Interest	Intervention	Comparator		Outcome	
				HQ for adult	HQ for children	HQ for adult	HQ for children
1	Biomonitoring of Water Bodies in Metro Manila, Philippines Using Heavy Metal Analysis and Erythrocyte Micronucleus Assay in Nile Tilapia (<i>Oreochromis niloticus</i>)	Class C freshwater in Tondo, Manila (Estero de Paco & Estero de Vitas)	One location is beside the public market while the other is near the Smokey Mountain	Cd = 3.07x10-4 Pb = 5.84x10-5	Cd = 3.49x10-4 Pb = 6.66x10-5	Cd = 1.11x10-1 Pb = 2.89x10-3	Cd = 1.27x10-1 Pb = 3.29x10-3
2	Assessing heavy metals in the waters, fish and macroinvertebrates in Manila bay, Philippines	Class C freshwater in the Las Piñas-Parañaque Lagoon	The secluded coastal lagoon of Manila Bay caters to many human activities and is connected to Pasig River	Cd = 3.07x10-4 Pb = 4	Cd = 3.49x10-4 Pb = 4	Cd = 1.45x100 Pb = 5.48x10-4	Cd = 1.65x100 Pb = 6.24x10-4



				5.84x10-5	6.66x10-5		4
3	Water Quality and Removal Efficiency of Suspended Solids, Copper, Lead, and Oil/Grease in Malihao River, Negros Occidental, Philippines using Bivalve Shells	Class C freshwater of Malihao River in Negros Occidental	increasing human activities along the river; Victorias Milling Company once issued a cease and desist order by DENR in 2013; various activities along the port such as shipping, tourism, and fishing	Cd = 3.07x10-4 Pb = 5.84x10-5	Cd = 3.49x10-4 Pb = 6.66x10-5	Cd = 1.15x10-3 Pb = 2.50x10-4	Cd = 1.31x10-3 Pb = 2.85x10-4
4	River flow pattern and heavy metals concentrations in Pasig River, Philippines as affected by varying seasons and astronomical tides	Class C freshwater along Pasig River in Manila	lead may have come from industrial wastes and vehicular emissions; other heavy metals may have come from many existing industrial activities along the river	Cd = 3.07x10-4 Pb = 5.84x10-5	Cd = 3.49x10-4 Pb = 6.66x10-5	Cd = 1.36x10-3 Pb = 3.38x10-4	Cd = 1.55x10-3 Pb = 3.85x10-4
5	Water Quality Assessment of Antiao River in Samar, Philippines	Class C freshwater of Antiao River in Catbalogan City, Samar	traces of copper have been found in Maqueda bay; industrial wastes and various anthropogenic activities	Cd = 3.07x10-4 Pb = 5.84x10-5	Cd = 3.49x10-4 Pb = 6.66x10-5	Cd = 4.71x10-5 Pb = 1.95x10-5	Cd = 5.36x10-5 Pb = 2.22x10-5
6	Heavy metals in surface waters of Laguna de Bay, Philippines: current levels and trends	Class C freshwaters of Laguna Lake	surrounded by densely populated areas, various industries and agricultural areas	Cd = 3.07x10-4 Pb = 5.84x10-5	Cd = 3.49x10-4 Pb = 6.66x10-5	Cd = 1.53x10-6 Pb = 1.33x10-6	Cd = 2.03x10-5 Pb = 1.77x10-5

Point of Interest

In this study, the P in PICO stands for Point of Interest, in which bodies of water, their classification, and their location are identified (Morgan et al., 2018). Since the study discusses the status of heavy metals in bodies of water in the country, these were either classified as fresh or marine in nature, or classified according to their intended beneficial use, as per DAO 2016-08 of DENR.

Freshwater. Freshwater is classified in DAO 2016-08 as bodies of water with no more than 500 ppm of dissolved sodium chloride. Some examples of these bodies of water are groundwater, rivers, lakes, and ponds. However, for this study, only rivers and lakes have been included.

Class C Waters. Class C Waters are those that have the most varied intended beneficial use under the DAO 2016-08. It is classified as such because it serves the purpose of Fishery Water for the propagation and growth of fish and other aquatic resources, recreational water for boating, fishing, and other non-direct contact activities (Recreational Water Class II), and for agricultural activities such as irrigation and livestock watering.

Study 1. This study tested the waters of Estero de Paco and Estero de Vitas in Tondo, Manila. Both rivers are tributaries of the Pasig River System and are surrounded by densely populated communities. Therefore, these are considered an important part of the ecosystem of the community.

Table 3. Point of Interest, Intervention, Comparator, and Outcome (PICO) Components of Studies (Oral)

Study No.	Title	Point of Interest	Intervention	Comparator		Outcome	
				adult	children	adult	children
1	Biomonitoring of Water Bodies in Metro Manila, Philippines Using Heavy Metal Analysis and Erythrocyte Micronucleus Assay in Nile Tilapia (<i>Oreochromis niloticus</i>)	Class C freshwater in Tondo, Manila (Estero de Paco & Estero de Vitas)	One location is beside the public market while the other is near the Smokey Mountain	Cd = 5.58x10-2 Pb = 1.59x10-1	Cd = 2.14x10-2 Pb = 6.12 x10-2	Cd = 2.02x101 Pb = 7.87x100	Cd = 4.76 x10-6 Pb = 1.85 x10-6
2	Assessing heavy metals in the waters, fish and macroinvertebrates in Manila bay, Philippines	Class C freshwater in the Las Piñas-Parañaque Lagoon	The secluded coastal lagoon of Manila Bay caters to many human activities and is connected to Pasig River	Cd = 5.58x10-2 Pb = 1.59x10-1	Cd = 2.14x10-2 Pb = 6.12 x10-2	Cd = 2.63x102 Pb = 1.49x100	Cd = 6.20 x10-5 Pb = 3.52 x10-7
3	Water Quality and Removal Efficiency of	Class C freshwater of	increasing human activities along the	Cd = 5.58x10-2	Cd = 2.14x10-2	Cd = 2.10x10-1	Cd = 4.94 x10-8



	Suspended Solids, Copper, Lead, and Oil/Grease in Malihao River, Negros Occidental, Philippines using Bivalve Shells	Malihao River in Negros Occidental	river; Victorias Milling Company once issued a cease and desist order by DENR in 2013; various activities along the port such as shipping, tourism, and fishing	Pb = 1.59x10 ⁻¹	Pb = 6.12 x10 ⁻²	Pb = 6.82x10 ⁻¹	Pb = 1.61 x10 ⁻⁷
4	River flow pattern and heavy metals concentrations in Pasig River, Philippines as affected by varying seasons and astronomical tides	Class C freshwater along Pasig River in Manila	lead may have come from industrial wastes and vehicular emissions; other heavy metals may have come from many existing industrial activities along the river	Cd = 5.58x10 ⁻² Pb = 1.59x10 ⁻¹	Cd = 2.14x10 ⁻² Pb = 6.12 x10 ⁻²	Cd = 2.48 x10 ⁻¹ Pb = 9.21 x10 ⁻¹	Cd = 5.83 x10 ⁻⁸ Pb = 2.17 x10 ⁻⁷
5	Water Quality Assessment of Antiao River in Samar, Philippines	Class C freshwater of Antiao River in Catbalogan City, Samar	traces of copper have been found in Maqueda bay; industrial wastes and various anthropogenic activities	Cd = 5.58x10 ⁻² Pb = 1.59x10 ⁻¹	Cd = 2.14x10 ⁻² Pb = 6.12 x10 ⁻²	Cd = 8.55 x10 ⁻³ Pb = 5.32 x10 ⁻²	Cd = 2.02 x10 ⁻⁹ Pb = 1.25 x10 ⁻⁸
6	Heavy metals in surface waters of Laguna de Bay, Philippines: current levels and trends	Class C freshwaters of Laguna Lake	surrounded by densely populated areas, various industries and agricultural areas	Cd = 5.58x10 ⁻² Pb = 1.59x10 ⁻¹	Cd = 2.14x10 ⁻² Pb = 6.12 x10 ⁻²	Cd = 2.79 x10 ⁻¹ Pb = 3.64 x10 ⁻³	Cd = 1.21 x10 ⁻⁹ Pb = 8.58 x10 ⁻¹⁰

Study 2. Metro Manila and the municipalities of Bataan, Bulacan, Cavite, and Pampanga in the southwestern part of Luzon landlock this area of Manila Bay. On April 22, 2007, a coastal lagoon along Manila Bay, Metro Manila, was identified and named the Las Piñas–Parañaque Lagoon by Proclamation No. 1412. This is identified as an important wetland in the country, making it a key biodiversity site for environmental conservation and sustainability.

Study 3. From Mt. Silay to the Guimaras Strait, the Malihao River spans 14.5km in Victorias City, Negros Occidental. Several locations were considered for the sampling of this body of water where the first is at the Malogo River, situated near a pumping station of Victorias Milling Company; the second is in Malihao Bridge where the Malihao River and the effluent of the aforementioned milling company converge; the third site, a tributary of the river under study, Magnanod River is considered; the fourth site is where the waters of Malihao River and Magnanod River mix; lastly, the waters of Daan Banwa Wharf is tested as this is where Malihao River ends and meets Guimaras Strait.

Study 4. The Pasig River is one of the world’s most polluted rivers and was once found to be unable to sustain life, according to Paronda et al. (2019). It traverses at least 6 municipalities in Metro Manila, spanning 27 kilometers and connecting Manila Bay and Laguna de Bay.

Study 5. Due to a lack of data on this river system, this study by Amascual et al (2024) classifies the Antiao River in Catbalogan City, Samar, Philippines, as Class C, which is the lowest level of water classification according to DAO 2016-08 that serves the following activities: agriculture, irrigation, livestock watering, and industrial supply.

Study 6. Laguna Lake is recognized as the largest freshwater lake in the country, with an average area of 90,000 Ha and a 220-km shoreline, serving dense communities. This inland body of water has an average depth of 2.5 meters, catering to a total volume of 3.2 billion cubic meters. Currently, LLDA (2024) reports that the lake has approximately 100 tributaries, including rivers and streams, of which 22 are significant contributors to Laguna Lake. The Napindan Channel is the only outlet of the lake, which flows through the Pasig River and drains into Manila Bay.

Intervention

“I” in the PICO framework stands for intervention. Although usually used to identify the intervention or exposure in the studies identified, the “I” in this systematic review provides information on how the environment changed because of the presence of heavy metals. The researchers in the included studies provided brief descriptions of the immediate environment and potential sources of heavy metals contributing to the identified bodies of water.

Study 1. 47 known estuaries drain into the notorious Pasig River in Metro Manila. Two of which are the focus of this study. Specifically,

Estero de Paco and Estero de Vitas. Heavy metal content was determined by Atomic Absorption Spectroscopy (AAS) with a minimum detection limit of 0.05 ppm.

While the Pasig River Rehabilitation Center conducted restoration efforts for Estero de Paco in 2010, there has been no testing for its genotoxic potential since then. This Estero is located near a public market, which the researchers consider a source of pollution leaching from market waste. In the study, it has been determined that heavy metals, lead and cadmium, were present, significantly exceeding the allowable standards set by DENR.

As for Estero de Vitas, this is situated near the Smokey Mountain. The mountain is named as such because it is a known dumpsite for various waste materials that could potentially leach heavy metals into this body of water. As of the study's 2019 conduct, no rehabilitation efforts have been undertaken on the latter Estero. The heavy metals lead and cadmium were found to exceed the DENR-allowed standard. Furthermore, compared to Estero de Paco, Estero de Vitas has a much higher heavy metal content, exceeding DENR's allowable standards for cadmium and lead by almost 200%.

The study also notes that the presence of heavy metals in the bodies of water has adverse effects on human health and on the mortality rates of fish and other aquatic organisms in the ecosystem. This also affects the consumption of fish from the area, which consequently has detrimental effects on the health of surrounding communities.

Study 2. In Manila Bay, the Las Piñas-Parañaque lagoon has been identified in study 2 as a protected area, as it is a critical habitat and an important wetland in the country. Inhabited by a diverse ecosystem of aquatic flora and fauna, it is constantly at risk of pollution from various anthropogenic activities in its immediate surroundings.

An Atomic Absorption Spectrophotometer (AAS) was used to detect the presence of heavy metals, with a minimum detection limit of 0.01 mg/L. In both wet and dry seasons, cadmium and lead were found to be present in all of the water samples collected from the lagoon. Compared to the DENR-allowable standards, there was a significant difference in the concentrations obtained.

As mentioned in the study, both cadmium and lead are classified as long-range transported air pollutants. With this, the pollution of the lagoon is attributed to direct atmospheric deposition of heavy metals and to other local point sources. The presence of these heavy metals in the body of water under study poses a threat to the aquatic ecosystem present within and around the Las Piñas-Parañaque lagoon. This also affects consumers of fish from the area, as these compounds are non-biodegradable and tend to bioaccumulate. According to Zhuzzhassarova et al. (2024), cadmium and lead are among the heavy metals that may cause poisoning in humans when consumed from fish and other aquatic products contaminated with these metals.

Study 3. Five sampling sites were identified for water sampling. The control site was located near a pumping station operated by the Victoria's Milling Company. The second site was identified at the Malihao Bridge, where the milling company's effluent passes through. The third site is along a tributary of the Malihao River, near various domestic and commercial establishments. The fourth site is where the waters from the Malihao River mix with those of the Magnanod River. Lastly, sampling site 5 is located within the area of Daan Banwa Wharf, where the Malihao River and the Guimaras Strait meet. Of these, the sampling sites with the highest levels of such heavy metals were Site 4, the mixing zone of rivers (Magnanod River and Malihao River), and Site 5, a high-traffic area for commercial shipping.

All sampling sites were seen to exceed the allowable standard set by DENR for lead in Class C bodies of water (0.05 mg/L). However, only Site 5 far exceeded the allowable value by more than 160%. Cadmium, on the other hand, was not detected in Sites 1 to 4 but was seen to exceed the allowable standard by almost 180%. The elevated levels of heavy metals in the Malihao River in Negros Occidental were directly attributed to various anthropogenic activities near the port, including commercial shipping, tourism, and fisheries.

Study 4. This study identifies four sampling locations along the Pasig River. The first sampling site is situated downstream of the river, where several barges and a large-scale glass manufacturing plant are present. The second sampling site is midstream on the river, near the Lambingan Station of the Pasig River Ferry Transport. Near the mouth of the Marikina River and the Napindan Hydraulic Control Structure, the third sampling station was identified. This area has many large-scale industries, including textile production, galvanized iron sheet production, food production, chemical production, and other consumer products. Lastly, the fourth sampling station is located upstream of the river near Laguna de Bay and the Marikina River. In this area, there are chemical and glass manufacturing plants. Furthermore, along the 27-km stretch of the Pasig River, many households are present, which greatly contribute to domestic waste in the river.

The results of the study indicate the presence of heavy metals in the the Pasig River. Of these, lead was seen to have the highest concentration (0.629 mg/L) downstream of the river during high tide during the dry season. This exceeds the allowable standard set for Class C bodies of water by more than 170%. On the other hand, the highest cadmium level (0.051 mg/L) was recorded during the same season, exceeding the allowable standard by more than 160%. The study attributes this to various point sources such as industrial wastes and vehicular emissions. Another possible explanation for this significant increase in the dry season is the backflow of the river, during which the solubilization of heavy metals may have occurred due to the formation of a salt wedge at the river mouth. This phenomenon may have caused the introduction of heavy metals into the body of water.

The lower concentration of heavy metals during the wet season, on the other hand, is attributed to the dilution effect of the water or the

dispersion of the heavy metals to Manila Bay.

Study 5. The Antiao River in Catbalogan City, Samar, Philippines, is a body of water discussed in Study 5 that has an upstream portion characterized by sandstone and limestone formations and mid- to downstream portions that are abundant with fertile soil. To test for the presence of cadmium and lead, the Direct Flame AAS method was used. It was found that although the heavy metal concentrations were above the minimum detection limit, they were still below the DENR standards.

The study notes that the river has been subjected to anthropogenic stresses in its surroundings, including shipping activities (navigation and fishing), irrigation and agriculture, and domestic and organic waste through surface water runoff from landfills. The presence of heavy metals poses a threat, as they tend to bioaccumulate, potentially entering the food chain and being ingested by humans.

Study 6. Laguna Lake lies between Metro Manila and the provinces of Laguna and Rizal. The study notes that the lake is surrounded by densely populated areas, where almost 16 million people depend on it for their day-to-day needs. The proponents of this study identify more than 1,100 industries, including hydroelectric power generation and industrial cooling, to name a few. Agricultural activities, such as aquaculture and irrigation, were also common in areas surrounding Laguna Lake as of 1990. These anthropogenic activities regularly produce waste that is unfortunately discharged directly into the lake, causing pollution by harmful heavy metals. This poses a threat not just to the quality of the water but also to the different organisms inhabiting the lake.

Heavy metal testing was done using inductively coupled plasma-mass spectrometry with method detection limits of 0.4 µg/L for lead and 0.05 µg/L for cadmium. It was then determined that the concentration of cadmium was below detection limits throughout the testing period. Lead, on the other hand, was found above the detection limit in January 2019. Despite this, the concentration of cadmium was still below the allowable standard set by DENR for Class C waters. In the following months, however, the cadmium concentration was found to be below the detection limit.

Comparator

The comparators used in the study are the standards or control values against which the study's results are compared as a point of reference (Heidel, 2024). The comparator values presented in Table 6 are the oral and dermal exposure hazard quotients calculated using the minimum allowable values of cadmium and lead as stated in DAO 2016-08.

Outcome

Water stress and scarcity are emerging problems in the Philippines, mainly due to untreated wastewater from domestic, industrial, and agricultural sources that is released into nearby bodies of water. Coastal and riverine communities are particularly affected by water pollution, specifically heavy metal pollution (GRID-Geneva, 2024).

The outcomes presented in this section of the study are the calculated hazard quotients based on the concentration of the heavy metals in the included studies. According to Parvin et al. (2022), an HQ value less than 1 does not pose a significant health risk. However, if HQ exceeds 1, adverse health effects may be widespread in the nearby community. The outcome is related to the policy brief that will be formulated at the end of the study. This is toward the assessment of the concentrations of heavy metals in relation to the human health risks involved.

Dermal Exposure

For the comparison of the dermal HQs of cadmium and lead, the table below shows that Studies 1, 2, 3, & 4 have HQ values that exceed the calculated HQs based on DENR standards for adults and children. Of these, data from Studies 1 & 2 show that the calculated HQ based on the measured cadmium concentration has exceeded the standard by almost 200%. This is the same for lead in Study 1. As for lead in Study 2, this exceeds the accepted HQ by 160%. Studies 3, 4, & 5 (cadmium only) have data for cadmium and lead that are seen to exceed the set standard by no more than 150%. Finally, Studies 5 (lead only) & 6, on the other hand, present data which are within acceptable limits for the HQs of cadmium and lead for both adults and children.

It is important to note that the hazard quotient of cadmium in Study 2 (1.448) for adults exceeded the allowable value of 1. In the same table, an emphasis on HQ for children indicates that the hazard quotients of cadmium in Studies 1 (1.4729) and 2 (19.205) pose a threat, as they exceed 1. These results collectively indicate the possibility of adverse non-carcinogenic health effects with chronic dermal exposure in its immediate community.

Oral Exposure

The Outcomes column in Table 3 presents the calculated Hazard Quotient (HQ) values for oral absorption of cadmium and lead, based on their actual concentrations from the selected studies.

The data show that the levels of cadmium and lead did not exceed the standards set for children, unlike those for adults in Studies 1, 2, 3, and 4. For the cadmium data in Studies 1 & 2, the calculated HQs based on actual data exceeded the allowable limit by almost 200%. The same percent difference is seen in lead for Study 1. However, the percent difference for cadmium and lead for studies 3 & 4 exceeded the allowable HQ by more than 110% but less than 150%. However, it is important to note that only lead in Studies 1 (7.87) and 2 (1.49) exceed the accepted value of 1, indicating that chronic exposure via ingestion of heavy metals poses a significant non-



carcinogenic health risk to the surrounding communities in these locations.

Meta-analysis of the Status of Heavy Metals on Bodies of Water in the Philippines

Test for Heterogeneity. Meta-analysis uses various tests for heterogeneity to assess the presence and degree of variation across the included studies (Buchan, 2024). This may be caused by various factors such as the characteristics of the participants, sampling sites, interventions implemented, methods used, or, in some cases, merely random error (Song et al., 2001). This study considers various tests for heterogeneity, including Cochran’s Q Test and Higgin’s I2 Statistic.

Cochran’s Q Test measures variation around the mean but does not yet assess heterogeneity among the studies (Kaur & Kaur, 2021). A high Q value indicates high heterogeneity among the included studies, and the opposite is true for low Q values. Regarding its associated p-value, it is not representative of the effect size and is therefore not indicative of the amount of heterogeneity. A low p-value merely indicates an unknown amount of heterogeneity across the studies collected. Borenstein et al. (2009) further support this by stating that the results of Cochran’s Q test and its associated p-value are mere tests for the significance of the variability and are not to be used as identifiers of the actual amount of variance among the studies.

A more definitive measure of heterogeneity is Higgin’s I2 Test Statistic. According to Borenstein et al. (2009), the I² index represents the proportion of observed variation that is real rather than by chance. It is scale-independent and is expressed as a ratio ranging from 0% to 100%. Further, it is essential to note that the value obtained from this test statistic is independent of the number of studies involved in the analysis. Higgins et al. (2011) in Cochrane Handbook for Systematic Reviews of Interventions Version 5.1.0 further elaborate the range for this statistic where 0-40% indicates an insignificant amount of heterogeneity; 30-60%, representing moderate heterogeneity; 50-90%, substantial heterogeneity; and 75-100% as considerable heterogeneity.

Once the presence and extent of heterogeneity have been identified, it is important to identify the sources of heterogeneity to draw proper conclusions in the meta-analysis. Often, a random-effects meta-analysis is conducted to address heterogeneity that cannot be thoroughly investigated through subgroup analysis or meta-regression (Siebert, 2018).

Table 4. Meta-Analysis Results of Studied Heavy Metals

Metals	Pooled Mean Estimate (in mg/L)	I-squared	Q	Degrees of Freedom	Heterogeneity p-value	Egger's Regression	Assymetry p	Rosenthal's Fail Safe N
Cadmium	11.36059762	99.97	578.011	5	< 0.001	9.122	< 0.001	305.000
Lead	0.31132287	99.76	282.064	5	< 0.001	4.324	< 0.001	395.000

Table 4 presents the results of the meta-analysis of the studies collected, which contain data on the presence of cadmium and lead in different Class C bodies of water in the Philippines. The presence of cadmium in Class C bodies of water yielded a Q statistic of 578.011 with 5 degrees of freedom. On the other hand, lead, with the same degrees of freedom, yielded a Q statistic of 282.064. For both heavy metals, the heterogeneity p-value is < 0.001. These results indicate heterogeneity among studies but do not determine its extent. Since the initial hypothesis of Cochran’s Q test indicates that the effect sizes are homogeneous, a p-value of < 0.001 disagrees with the initial assumption and points toward the presence of heterogeneity among effect sizes. For Higgin’s I2 test, a considerable level of heterogeneity was obtained for both heavy metals. This means that the heterogeneity in the collected SMD effect size estimates is due to sampling error within the studies and not just due to chance (Huedo-Medina et al., 2006)

The heterogeneity must then be considered when formulating conclusions for this study, and a further subgroup analysis should be conducted to possibly identify the sources of this heterogeneity.

Forest Plot. A forest plot is a graphical representation of the results of a meta-analysis in which different studies are combined to answer the same research question (Lalkhen, 2008). It contains the studies included in the analysis, with their corresponding weights, and the outcome effect measure, presented in both numeric and graphical form (Dettori et al., 2021).

This study considers standardized mean difference effect sizes, calculated using Cohen’s d and the standard errors for each effect size, to formulate the forest plots. With this, the data on the right-hand side of the graph indicate the individual study weights and the mean difference with its 95% confidence interval (CI). The vertical line in the middle of each forest plot below indicates the no-effect line at 0, as continuous outcomes are considered in this study. According to Dettori et al. (2021), this line, when crossed by the 95% CI line of each study, indicates that there is no significant difference between the outcomes of the intervention (actual data on the concentration of heavy metals) vs the comparator (accepted data based on DAO 2016-08).

In each forest plot, the black squares represent the effect size of each study. The size of the box depends on the number of samples taken for each study, with larger boxes representing a larger sample size and smaller boxes a smaller one. The size of the square is also inversely proportional to the range of the confidence interval. Larger boxes correspond to narrower confidence intervals, and smaller boxes correspond to wider confidence intervals. This means that large sample sizes are less likely to cross the line of no effect, while smaller sample sizes are more likely to cross it (Cantley, 2016).

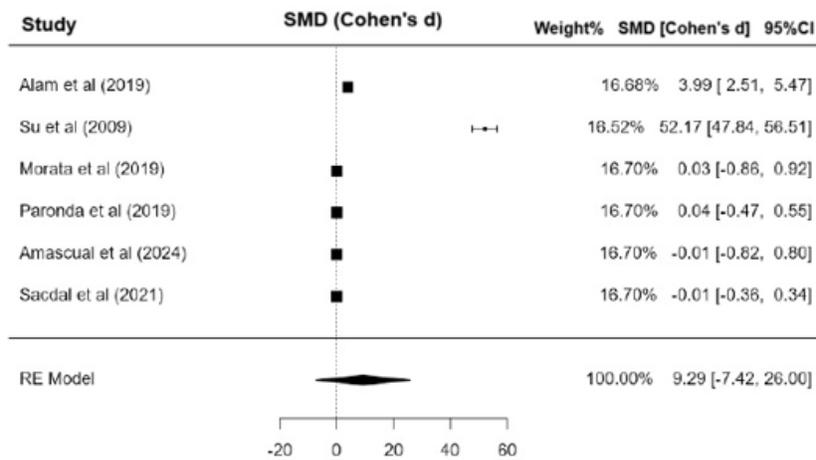


Figure 1. Forest Plot for SMD of Cadmium in Selected Class C Bodies of Water in the Philippines

Cadmium. Based on the meta-analysis results, the largest standardized mean difference (SMD) for cadmium across all bodies of water in the Philippines is in Manila Bay (52.17 [47.84, 56.51]). This area is known to be surrounded by various commercial and municipal establishments, which contribute to untreated wastewater being deposited into the bay. Apart from this, Metro Manila is a source of various local point sources of heavy metals and is a recipient of heavy metal deposition from air pollution. Meanwhile, the lowest SMD for cadmium, across both marine and fresh bodies of water in the Philippines, is in Laguna de Bay (-0.01 [-0.36, 0.34]), where cadmium levels were below the detection limit. Based on the Random Effects Model, the SMD for all bodies of water in the country is 9.29 [-7.42, 26.00], which means that the levels of cadmium for the bodies of water tested have an average that leans towards the right of the line of null effect, indicating a slight excess in its levels.

Given that the overall levels of cadmium in the country exceed the DENR's allowable standard, this is attributed to various anthropogenic activities, such as mining. The deposition of cadmium from the combustion of fossil fuels and agricultural activities using phosphate fertilizers, which are known to contain cadmium (Kubier et al., 2019). Another possible source of cadmium is landfills, where municipal solid waste is regularly deposited. The improper segregation and handling of such wastes could include nickel-cadmium batteries and other cadmium-containing products such as pigments, coatings, and plastics (ATSDR, 2023). Acute oral ingestion may cause symptoms similar to food poisoning, which may include abdominal cramps, vomiting, salivation, and diarrhea (ATSDR, 2023). According to a review on cadmium toxicity by Rafati-Rahimzadeh et al. (2017), on the other hand, chronic exposure may lead to early signs of renal damage, calcium loss, and an increased risk of high blood pressure. Special cases of prolonged exposure to this heavy metal have been known to cause itai-itai disease, a condition characterized by symptoms such as osteomalacia, severe bone pain, and renal tubular dysfunction (Nishijo et al., 2017). Furthermore, cadmium, being a group 1 carcinogen, as classified by the IARC (2024), is known to cause different types of cancers and organ toxicity in various organ systems of humans, such as the skeletal, urinary, and cardiovascular systems, to name a few.

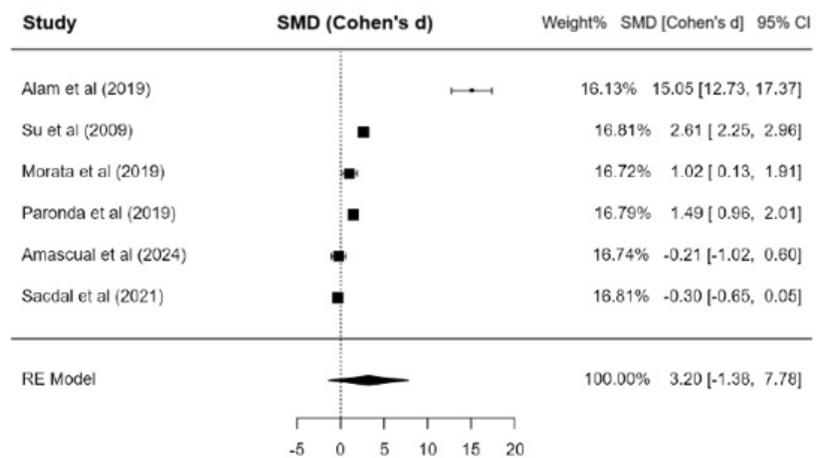


Figure 2. Forest Plot of SMD of Lead in Selected Class C Bodies of Water in the Philippines

Lead. The highest SMD for lead, considering both marine and fresh bodies of water, is in Tondo, Manila (15.05 [12.73, 17.37]), while the lowest among the studies is in the Antiao River, Samar (-0.21 [-1.02, 0.60]). The overall SMD for all lead across all included bodies of water is 3.20 [-1.38, 7.78], indicating that overall lead levels exceed the DENR-allowed standards. Metro Manila is among the most

densely populated areas in the world, as it is inhabited by an average of 71,000 people per km² (delos Reyes et al., 2020). Because of this overpopulation, water bodies in Metro Manila have become notorious for their pollution level. Although unintended, these bodies of water have become dumping grounds for communities' municipal and domestic waste (DENR EMB, 2023).

Lead contamination may be caused by various activities, such as shipping, in which contamination may result from repair and maintenance activities on ships that use paint and welding equipment (Jimenez et al., 2018). Furthermore, the close proximity to a densely populated area may lead to contamination from leaded gasoline in vehicles and from improperly treated industrial and domestic waste before discharge into bodies of water. Another common cause of lead contamination in water is the corrosion of lead plumbing, such as lead service lines, lead-soldered joints, and other lead-containing plumbing fixtures (Mulvihill, 2023). Although lead is only classified by the IARC (2006) as 2A, meaning that these substances may cause cancer, it still poses a significant threat to society because of its bioaccumulative property as a heavy metal. According to the CDC (2024), there is no identified safe blood lead level for children. It is known to cause various illnesses, specifically to the brain, as lead is known to be a neurotoxicant to the developing brain, causing cognitive impairment and decreased IQ (American Academy of Pediatrics, 2024). According to ATSDR (2023), adults dealing with chronic lead exposure may experience various adverse neurological conditions, such as cognitive and executive problems, abnormal social behavior, and difficulties with fine motor skills. Latent effects of lead exposure may also appear in adulthood through renal problems and kidney disease. Mayo Clinic (2022) further adds that children are at a higher risk of the effects of lead poisoning, as ingestion of high doses of lead may cause developmental delay, abdominal pain, vomiting, constipation, and seizures, to name a few. For adults, lead poisoning may lead to hypertension, cognitive effects, reduced and abnormal sperm, and possibly miscarriage.

Publication Bias. To assess publication bias, this study uses a funnel plot, a scatter plot that compares each study's intervention effect estimate with its standard error or precision (Higgins, 2011). Each study included is represented as a dot. With smaller studies involved, the dots are expected to be scattered widely at the bottom of the plot. In contrast, with more significant studies included, these tend to narrow toward the top, increasing precision and clustering closer to the overall estimate (Syed, 2023). In the absence of bias and if the included studies' effect sizes are sufficient, the overall shape of the plot should resemble a symmetrical inverted funnel. Otherwise, an asymmetrical plot would appear if there were bias or other sources of heterogeneity. This asymmetry would then become more pronounced as the amount of bias increases (Higgins, 2011; Sterne & Harbord, 2004).

For this meta-analysis, funnel plots for each heavy metal across different bodies of water are presented, with the standardized mean difference on the x-axis and the standard error of the individual studies on the y-axis. Due to the asymmetry seen in the funnel plots collated in Figure 3, the possibility of publication bias is present in some relationships. A large magnitude of Egger's statistic indicates strong evidence of publication bias. However, in conjunction with its associated p-value, the statistical significance of the asymmetry is confirmed: a p-value less than 0.05 indicates that the result is statistically significant, while a value greater than 0.05 indicates that the observed asymmetry may be statistically insignificant (Egger et al. 1997). Egger's Regression test statistic confirms publication bias for cadmium ($\beta = 9.122$, $p < 0.001$) and lead in the included studies ($\beta = 4.324$, $p < 0.001$). Although the funnel plots appear asymmetrical, these do not solely correlate to publication bias, as indicated by the results of Egger's regression test. Distiller SR (2024) states that the sources of asymmetry may be attributed to small-study effects and heterogeneity.

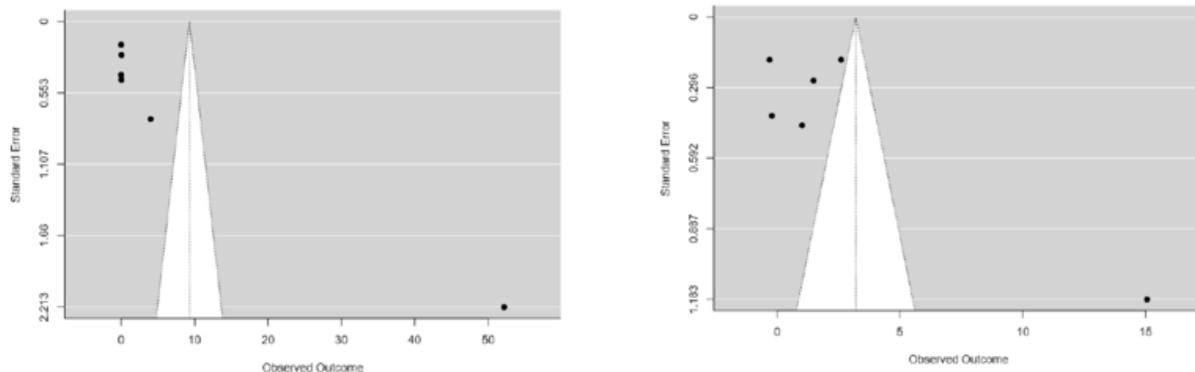


Figure 3a and 3b. *Funnel Plot of Cadmium and Lead for Assessing Publication Bias*

For this meta-analysis, the funnel plots for each heavy metal in different bodies of water are presented with the standardized mean difference on the x-axis and the standard error of the individual studies on the y-axis. Due to the asymmetry seen in the funnel plots collated in Figure 3, the possibility of publication bias is present in some relationships. A large magnitude of Egger's statistic indicates strong evidence of publication bias. However, in conjunction with its associated p-value, the statistical significance of the asymmetry is confirmed: a p-value less than 0.05 indicates that the result is statistically significant, while a value greater than 0.05 indicates that the observed asymmetry may be statistically insignificant (Egger et al. 1997). Egger's Regression test statistic confirms publication bias for cadmium ($\beta = 9.122$, $p < 0.001$) and lead in the included studies ($\beta = 4.324$, $p < 0.001$). Although the funnel plots appear asymmetrical, these do not solely correlate to publication bias, as indicated by the results of Egger's regression test. Distiller SR (2024) states that the sources of asymmetry may be attributed to small-study effects and heterogeneity.

Another method of checking for publication bias is Rosenthal's Fail-Safe N, which indicates a robust meta-analysis that would not be easily overturned by adding a small number of studies. This means publication bias would not easily affect the meta-analysis (Yurt & Polat, 2015).

The main limitation of this study is that the included studies spanned different time periods. This means that bodies of water have changed over time due to various factors, such as the dilution effects of varying rainfall amounts, the dilution effects of global warming, increased chemical pollution from anthropogenic activities, and other climatic disturbances (Banfalvi, 2023). Furthermore, the collection of studies includes various areas that were not classified, whether in a rural or an urban zone, and this was not identified during the conduct of the study.

Conclusions

This section synthesizes the core findings of the systematic review and meta-analysis conducted. This also highlights the significance of the results in advancing knowledge within the field. Lastly, it concludes with recommendations for policy improvement and future research, offering specific avenues for further studies in line with this topic.

Based on the systematic review and meta-analysis of the six (6) studies included, it can be concluded that the selected heavy metals in different bodies of water pose adverse health risks to communities chronically exposed to them. The different bodies of water in the archipelago are exposed to varying levels of heavy metals depending on their surrounding anthropogenic activities. As evidenced by the forest plot, the identified heavy metals lie to the right of the null line, indicating a slight to moderate excess of allowable levels for DENR-set bodies of water. With this, there is a pressing need for continuous monitoring of heavy metal levels in Philippine water bodies to enable appropriate action when needed.

The presence of heavy metals in bodies of water across the country poses a threat to the quality of life of communities. It can cause adverse health effects on affected communities, which is why interventions are important as soon as possible to prevent further damage. It is necessary to inform the community about the causes and consequences of these pollutants so that adequate regulations and safeguards can be implemented to improve the community and the environment.

Intensive efforts to educate the community should be made to raise awareness and remind them of the harmful effects of heavy metal pollution in water and what can be done to prevent it. Furthermore, community involvement would play a vital role, as members would be provided with practical steps and hands-on experience in the roles they can participate in.

Continuous monitoring of bodies of water can provide real-time data on heavy metal levels. In line with this, research on this topic can be encouraged in different sectors of the community. This can add to the existing body of knowledge, providing more information and data that can then be used to develop improved policies that cater to the rising needs of communities.

For waste generators in the community, stricter regulations and more targeted policies may be implemented to address the handling of their waste. Policies on solid waste management should be strictly enforced in communities, and wastewater treatment facilities should be improved and kept up to date to ensure their functionality.

Lastly, LGUs can formulate and implement data-driven policies and programs that ensure the sustainability of actions toward taking care of the environment. In line with these findings, the development of and dissemination of the proposed policy brief is recommended to address the challenges faced and improve current practices in local communities.

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