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A PRELIMINARY HEALTH RISK ASSESSMENT OF HEAVY METALS VIA INGESTION AND DERMAL ABSORPTION OF WATER IN THE AGUSAN RIVER, MINDANAO, PHILIPPINES

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ABSTRACT

Heavy metal-contaminated water can threaten community health. This study assessed human exposure to four heavy metals: copper, nickel, chromium, and total mercury in the Agusan River via ingestion and dermal routes for adults and children. Using secondary sediment data. Chronic daily intakes (CDI) were computed, and US EPA reference doses were used to calculate hazard quotients (HQ) and hazard index (HI), as well as lifetime cancer risk (CR). All HQs and HIs were below <1. Ingestion HIs (10^{-6} for both age groups) indicate negligible oral risk. Dermal HIs reached 0.07–0.13 in adults and 0.08–0.16 in children at the downstream site, still well below 1. No HI exceeded 1. Cancer-risk show for Cr were below $<10^{-6}$, far below EPA concern. These findings show that Agusan River water poses no significant non-cancer or cancer risk under current conditions. However, continued pollution control and monitoring are recommended due to the presence of bioaccumulation, which allows toxins such as heavy metals to reach hazardous levels in organisms over time.

Keywords: *Agusan River; heavy metals; health risk assessment; Hazard Index; ingestion; dermal exposure*

INTRODUCTION

Heavy metal pollution from mining, smelting, and industrial waste has increasingly contaminated freshwater areas, which creates a serious threat to ecosystems and especially to human health (Järup, 2003; Titilawo, Soneye, & Adeleke, 2018). Even the trace of low levels of toxic elements can be harmful for humans; for example, cadmium and lead are highly toxic at low concentrations and bioaccumulate over time in body tissues (Järup, 2003). Many heavy metals continue to pollute the environment and can enter the human body through water, food, or even through the skin, which can cause chronic effects such as cancer, organ failure, and even neurological impairment over a lifetime. (Toxicological profiles. 2025; WHO, 2011). These specific types of global concerns are urgent where large populations, such as in mindanao depend directly on rivers and lakes for drinking, cooking, bathing, and fishing (Xavier University - Ateneo de Cagayan, 2025).

This global problem occurs in developing countries, where safe water systems are very limited. Specifically, the World Health Organization reports that roughly two billion people worldwide lack safely managed drinking water, forcing many communities to rely on contaminated waters (WHO, 2011). These communities often face challenges of vulnerability and environmental unfairness; poor and marginalized groups are affected by water pollution because they only have a few options and limited resources (Liang, 2017; Mariano, 2019). In these settings, it shows that the increasing water contamination directly affects public health and environmental equity issues. Where clean water is scarce, and the community is forced to use contaminated water, which may be used for domestic needs, implying risks to adults and especially to children.

In the Philippines, river use is still widely practiced, especially in rural regions, despite the constant pollution. The Agusan River in Caraga, within northeastern Mindanao, is a major example of a river that communities highly depend on for domestic uses such as household water, fishing, and even agriculture. Recent data in the lower Agusan River have reported increased levels of metals, including copper (Cu), nickel (Ni), total mercury (tHg), and chromium (Cr) (Cabuga et al., 2019). In fact, Cabuga et al. (2019) found that the secondary data of Cr, Ni, Cu, and tHg in the Agusan River failed international safety limits, showing potential areas of high contamination. These findings suggest potential health hazards, yet people continue to use the river for daily use, and no prior study has turned this data into a usable formal human health risk assessment, which people are in need of, to have an awareness and proof of the environmental equity and their vulnerability.

This study showcases an international standardized method for turning river contamination data into clear and usable human-health risk estimates, rather than just plain numerical data of the contamination. Utilized and applied in the Agusan River, this approach uses contamination data testing with a step-by-step way of estimating how people are exposed to contaminants and what areas of risk they might face over time. It provides results that are easy and usable to compare across different communities, making it easier to see where risks are higher compared to others. Because the method follows a clear and constant process, it can be used by researchers, government agencies, local groups, or even people to spot what areas are highly affected so they know where they might focus on monitoring, having clean-up efforts, or even health campaign programs. This study demonstrates how this method can be applied and utilized not just in one river but in many others, helping turn raw numerical contamination data into useful information. Making it easier to use across different areas and more helpful for planning and developing solutions.

For this study, we focused on four specific heavy metals: tHg, Cu, Ni, and Cr. This was chosen due to their increased level of contamination and their effects. tHg, released primarily by gold mining, is a dangerous neurotoxin that accumulates in the human body when exposed. In the Agusan River, gold mining in the Diwalwal district is known to introduce high tHg. Downstream surveys found waterborne tHg up to 2900 µg/L and sediment tHg exceeding 20 mg/kg, which is far above EPA concern (Appleton et al., 1999). Copper, on the other hand, enters rivers from mining and industrial activities, though an essential nutrient, excess Cu can cause organ damage such as gastrointestinal and hepatic damage. While Ni exposure, from mining, stainless steel production, and industrial waste, remains a health concern that can trigger allergic contact, irritate the lungs and nasal passages, and is proven to be a potential carcinogen. Lastly, Cr is often spread by tanneries and metal processing plants; it is highly carcinogenic and can cause skin, respiratory, systemic, and organ damage. Each of these heavy metals is a concern in Mindanao: tHg from gold mining, Cu and Ni from mining and mineral activities, and Cr from industrial activities. The Agusan River, one of Mindanao's major water sources, plays a role in communities, agriculture, fisheries, and ecosystems, making the assessment of this heavy metal contamination needed for the public and the environmental health.

Despite the constant contamination, no prior paper has conducted a human health risk assessment for heavy metals in the Agusan River using international standard criteria, such as those from the U.S. EPA. Prior work (e.g., Cabuga et al., 2019) has documented sediment contamination of the Agusan River itself, but has not shown actual human exposures or risk metrics for people to use. This gap leaves unanswered questions about the potential health impacts on adults and especially the children. This study addresses this gap by applying a quantitative human-health risk assessment to existing sediment data, converting these measurements into usable information to determine the chronic daily intake (CDI), hazard quotients (HQ), hazard index (HI), and lifetime cancer risk (CR) to identify which specific areas can become a public health problem.

To evaluate these hazards, environmental health studies commonly use quantitative risk-assessment methods based on the international U.S. EPA criteria. These method determines exposure doses by relevant pathways of the human body by ingestion of water, dermal absorption through the skin, or inhalation of gases or particles. For each contaminant and pathway, the HQ is computed as the ratio of the exposure dose to a reference dose for that contaminant. The reference dose is a health-based threshold from the U.S. EPA, which estimates the daily intake that is unlikely to cause effects over a lifetime. If the HQ is less than 1, the non-cancer risk is considered negligible, but if it is higher than 1, there is a potential for hazardous effects. When multiple contaminants and pathways are involved, the HI, the sum of the individual HQ, provides if one is affected by the non-carcinogenic risk. For carcinogenic contaminants, one must get the CDI and multiply it by a cancer slope factor (CSF) to yield a gradual CR. The CSF from the U.S. EPA shows the probability of cancer per unit dose, allowing estimation of lifetime cancer risk from chronic exposure. These metrics form the international standard quantitative health-risk assessment for heavy metals in water (USEPA, 1989, 2011).

U.S. EPA risk equations, such as CDI, HQ, HI, and CR, are metrics that use contaminant concentrations in water (mg/L) because they estimate exposure through ingestion and contact with water (USEPA, 1989, 2011). But, due to the unavailability of data in the Agusan River, the data focused on sediments, reported in mg/kg, rather than from the water. Because of this, the sediment data could not be used in the standard U.S. EPA metrics. To address this, the sediment concentrations were first converted into water concentrations using a mass to volume conversion based on an assumed sediment bulk density of 1.3 g·cm-3 (Soil Survey Staff, 2024). While this conversion allows the application of the U.S. EPA risk assessment, the results of this study should be interpreted with caution, as they are based on converted data rather than direct measurements. For this reason, the findings are considered preliminary and are intended to provide an initial understanding of risks.

METHODS

Study Site

This study was derived from the data along the lower Agusan River, in northeastern Mindanao. The Agusan River is widely used as a resource for fisheries, transportation, agriculture, and domestic uses across Agusan del Sur, Agusan del Norte, and Butuan City. Despite its importance, the lower Agusan River is increasingly exposed to pollution from mining, smelting, and industrial activities. These conditions make the Agusan River an important site for assessing the potential human health risks caused by the heavy metals.

This study used the sediment concentration data reported by Cabuga et al. (2019) for three stations along the Agusan River, which are freshwater, brackish water, and marine water as a secondary data source; this study neither conducted nor replicated the sampling. The mean sediment values reported by Cabuga et al. (2019) were used as concentrations for our risk assessment and were converted from mg/kg (sediment) to water concentrations to estimate the contamination into human-health risk metrics (CDI, HQ, HI, and CR) without new sampling.

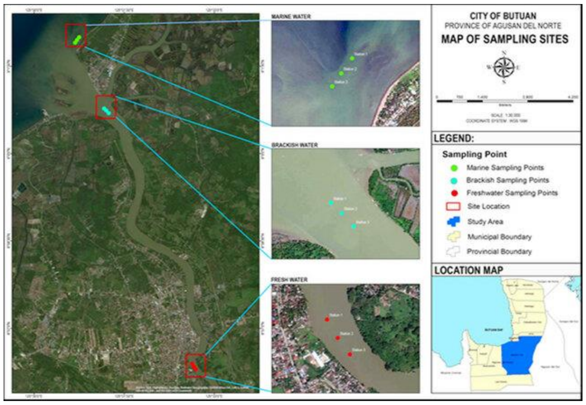

Figure 1. Location of Map Sampling Sites (Source: Cabuga et al. 2020)

Table 1. Sampling Sites in Agusan River during April-May 2018 (Cabuga et al. 2019)

Site Station	Station Identification	Geographical Coordinates	
Fresh Water Station	Downstream of Brgy. Buhangin, Butuan City	8°56'16.3"N	125°32'46.9"E
Brackish Water Station	Brgy. Pagatpatan, Butuan City	9°00'34.1"N	125°31'12.5"E
Marine Water Station	Brgy. Dahekan, Magallanes, Agusan del Norte	9°02'04.5"N	125°30'49.9"E

The secondary data from Cabuga et al. (2019) was utilized because it has sampling stations that have different types of water sources, including freshwater, brackish water, and marine water. For each station, three samples were collected and averaged within the area, making the data more reliable and consistent. This allows the study to know how heavy metal contamination varies across these different conditions. The study applies these data to assess potential human health risks through ingestion and dermal exposure. Table 1 summarizes the sampling sites and their characteristics.

Human Health Risk Assessment

This study uses the U.S. EPA Human Health Risk Assessment (HHRA) process to evaluate the potential health effects from tHg, Cu, Ni, and Cr in the lower Agusan River. Following the standard U.S. EPA HHRA step-by-step process It starts with hazard identification, exposure assessment, and then risk characterization. The study estimates the CDI for two pathways, which are ingestion and dermal absorption, and two population groups, which are adults and children. Non-cancer risk is indicated by HQ and summed as HI. While the cancer risk is indicated by CR, which is estimated by multiplying CDI by the CSF. These results will identify stations and populations of greatest concern and provide a basis for which to monitor.

Hazard Identification

The first step of HHRA is to identify the hazardous contaminants and their adverse effects. In this study, we focus on four heavy metals, which are tHG, Cu, Ni, and Cr, and gathered data from Cabuga et al. (2019) in the lower Agusan River, which contained increased levels of these metals, with Cr and Cu being the highest concentrations. Heavy metals are constant environmental contaminants that can bioaccumulate and cause serious health problems. For example, exposure to tHg or Ni can have adverse effects on cellular functions and lead to poisoning. We therefore chose tHg, Cu, Ni, and Cr as the main contaminants in this study.

Exposure Assessment

The second step of HHRA is exposure assessment, which measures how much of each heavy metal people might ingest or absorb through the skin. We utilized two exposure pathways, which are oral ingestion and dermal absorption, and two life stages, which are children and adults. The water-equivalent contaminants were then used as the concentration in the CDI calculations for both ingestion and dermal pathways (Mariano, 2019).

Table 2. The definition and value of exposure parameters (Liang et al., 2017; Titilawo et al., 2018; Mariano, 2019)

Parameter	Definition	Adult	Children
C	Heavy metal concentration in water (mg/L)	—	—
IR	Ingestion rate of the water being studied (L/day)	2.5	0.78
ED	Exposure duration (years)	26	6
EF	Exposure frequency (days/year	350	350
CF	unit conversion factor (L/cm^3)	0.000001	0.000001
BW	Average body weight (kg)	80	15
AT	Average time (days)	25500	25500
AF	Skin adherence factor (mg/cm^2)	0.07	0.2
SA	Exposed surface area of skin (cm^2)	19652	6365
ABS	Dermal absorption factor	0.1	0.1
SF	Carcinogenicity slope factor (mg/kg/day) (Cu)	n/a	
	Carcinogenicity slope factor (mg/kg/day) (Pb)	0.0085	
	Carcinogenicity slope factor (mg/kg/day) (Cd)	0.38	
	Carcinogenicity slope factor (mg/kg/day) (Cr)	0.5	
RfD	Chronic Oral reference dose (mg/kg/day) (Cu)	0.04	
	Chronic Oral reference dose (mg/kg/day) (Pb)	0.0036	
	Chronic Oral reference dose (mg/kg/day) (Cd)	0.001	
	Chronic Oral reference dose (mg/kg/day) (Cr)	0.003	
	Chronic dermal reference dose (mg/kg/day) (Cu)	0.012	
	Chronic dermal reference dose (mg/kg/day) (Pb)	0.000525	

Note: $CDI_{\{dermal\}} = \frac{(C_w \times SA \times K_p \times ET \times EF \times ED \times CF)}{Bw \times AT}$ $CDI_{\{ingestion\}} = \frac{(C_w \times IR \times EF \times ED)}{Bw \times AT}$

Risk Characterization

The third step of HHRA is risk characterization, which uses the CDI with parameters sourced from USEPA's Integrated Risk Information System (IRIS) to estimate the potential human health effects in non-cancer and cancer risk. In this study, two evaluations were used for each metal, pathway by ingestion and dermal, and population group by adults and children (USEPA, 1989; Titilawo et al., 2018).

For non-carcinogenic risk, it compares the estimated CDI of a contaminant with its Rfd. It is calculated as: $HQ = CDI / RfD$. An HQ < 1 indicates unlikely to cause non-cancer adverse effects. An HQ ≥ 1 suggests concerns and requires attention. When multiple contaminant exposure pathways are present, such as the four heavy metals chosen in this study, individual HQs are summed to provide an HI, which is indicated as the combined non-cancer risk from multiple contaminants being exposed to. The parameters are HI < 0.1 (negligible), 0.1–1.0 (low), 1.0–4.0 (medium), and > 4.0 (high), which are cited by Kamunda et al. (2016) and in Mariano (2019).

For Carcinogenic risk, we only chose Cr and Ni as the heavy metals due to their being carcinogens. The lifetime cancer risk is estimated by multiplying the lifetime CDI by the CSF: $CR = CDI \times CSF$.

The parameters for lifetime cancer risk are between 1×10^{-6} and 1×10^{-4} as an acceptable range. Values below 1×10^{-6} are considered negligible, and values above 1×10^{-4} are unacceptable (USEPA, 2011).

The overall methodological approach of this study, from the secondary data gathering to the HHRA process of potential health risks, is summarized in Figure 2 below.

Figure 2. Flowchart of the overall methodological process for the Agusan River.

RESULTS AND DISCUSSION

Concentration of Heavy Metals in the Sediment

The first step of HHRA is identifying the heavy metals that will be used in this study. The sediment heavy metal concentrations gathered from Cabuga et al. (2019) for the Lower Agusan River were used as the data for this study's risk assessment. These heavy metals Cu, Ni, Cr, tHg are in mean values at three different stations, including freshwater, brackish water, marine water, and were converted to water-equivalent values or mg/L by assuming a sediment bulk density of 1.3 g/cm³. These values are then compared below to the allowable limits established in DAO No. 2016-08 to assess their safety.

Table 3. Heavy Metal Concentrations Converted to mg/L Assuming an Average Soil Bulk Density of 1.3 g/cm³

Heavy Metal	Standard (mg/L)	Fresh Water		Brackish Water		Marine Water	
		mg/kg	mg/L	mg/kg	mg/L	mg/kg	mg/L
Cu	0.02	56.22	73.086	60.78	79.014	35.78	46.514
Ni	0.2	43.22	56.186	48.67	63.271	88.78	115.414
Cr	0.01	77.56	100.828	76.67	99.671	98.33	127.829
tHg	0.002	0.21	0.273	0.77	0.1001	BDL	BDL

*Note: *BDL - Below Detection Limit*

Based on Table 3, the findings reveal that the Cu, Ni, Cr, and tHg exceeded the limits set by the Department of Environment and Natural Resources (DENR, 2016). Cr and Ni show especially high concentrations at the marine station. On the other hand, tHG is highest at the freshwater station and exceeds detection limits at the marine site. Copper is elevated across sites but shows a decline toward the marine station. These increased levels of heavy metals, show long term bioaccumulation of contaminants in aquatic organisms or the environment, and a constant risk of pollution into the water. This then increases exposure to nearby communities in Mindanao through both ingestion and dermal contact. Meaning there is inadequate and ineffective monitoring throughout the three stations, affecting both the ecosystem and human health.

Health Risk Assessment

Chronic Daily Intake

The second step of HHRA is calculating the daily intake a person might ingest or absorb. Starting with the calculated CDI via ingestion for Cu, Ni, Cr, and tHg that people might ingest throughout their lifetime, which are shown in Tables 4 and 5.

Table 4. Heavy Metal Intake Through Ingestion (CDI ingestion) for Adults

Heavy metal	Freshwater	Brackish water	Marine water
Cu	8.0×10^{-7}	9.0×10^{-7}	5.0×10^{-7}
Ni	6.0×10^{-7}	7.0×10^{-7}	1.3×10^{-6}
Cr	1.1×10^{-6}	1.1×10^{-6}	1.4×10^{-6}
tHg	3.0×10^{-8}	1.0×10^{-8}	BDL

Note. BDL = Below detection limit.

Table 5. Heavy Metal Intake Through Ingestion (CDI ingestion) for Children

Heavy metal	Freshwater	Brackish water	Marine water
Cu	3.0×10^{-7}	3.0×10^{-7}	2.0×10^{-7}
Ni	2.0×10^{-7}	3.0×10^{-7}	5.0×10^{-7}
Cr	4.0×10^{-7}	4.0×10^{-7}	5.0×10^{-7}
tHg	1.0×10^{-8}	4.0×10^{-9}	BDL

Note. BDL = Below detection limit.

For both adults and children, the highest ingestion CDIs are Ni and Cr, with the marine station indicating the highest values for these two metals. While for Cu is minor, and tHG ingestion is negligible given its small value. These ingestion CDIs remain below the U.S. EPA oral RFD for heavy metals, indicating that these ingestion values are unlikely to cause non-carcinogenic risk under the exposure parameters used. Even so, based on the data given, children are more vulnerable than adults because of their higher doses per body weight, so even low CDIs still need to be monitored closely.

Table 6. Heavy Metal Intake Through Ingestion (CDI Dermal) for Adults

Heavy metal	Freshwater	Brackish water	Marine water
Cu	4.48×10^{-4}	4.85×10^{-4}	2.85×10^{-4}
Ni	3.45×10^{-4}	3.90×10^{-4}	7.08×10^{-4}
Cr	6.00×10^{-4}	6.00×10^{-4}	8.00×10^{-4}
tHg	2.00×10^{-6}	1.00×10^{-6}	BDL

Note. BDL = Below detection limit.

Table 7. Heavy Metal Intake Through Ingestion (CDI Dermal) for Children

Heavy metal	Freshwater	Brackish water	Marine water
Cu	5.11×10^{-4}	5.52×10^{-4}	3.25×10^{-4}
Ni	3.93×10^{-4}	4.44×10^{-4}	8.07×10^{-4}
Cr	7.00×10^{-4}	7.00×10^{-4}	9.00×10^{-4}
tHg	2.00×10^{-6}	1.00×10^{-6}	BDL

Note. BDL = Below detection limit.

Next up are the Dermal CDIs, which are values that humans might absorb through their skin daily, and are larger values than the ingestion CDIs due to their larger exposed surface area (Exposure Assessment Tools by Routes - Dermal | US EPA, 2025). Tables 6 and 7 show that Ni and Cr again show the highest dermal CDIs, with it still being highest in the marine water station, while Cu shows moderate dermal CDIs, and tHG shows negligible due to its small value. When compared to the U.S. EPA dermal RFD, these values are below the study's parameters, but combined exposures and repeated contact, especially among children, still need to be investigated further and monitored.

Hazard Quotient

The third step of HHRA is getting the HQ, which gives data on whether non-carcinogenic risk can be seen. Each HQ for each metal is measured as the ratio of its CDI to the U.S. EPA RfD. In other words, HQ = CDI/RfD (Mariano, 2019). By U.S. EPA Rfd, HQ values below 1 are unlikely to cause adverse effects, whereas HQ ≥ 1 indicates a potential health concern. We calculated HQs for Cu, Ni, Cr, and tHG for adults and children via ingestion and dermal absorption. These are shown in Tables 8-11.

Table 8. Hazard Quotient for Adults via Ingestion Pathway

Heavy metal	Freshwater	Brackish water	Marine water
Cu	2.00×10^{-5}	2.25×10^{-5}	1.25×10^{-5}
Ni	1.67×10^{-4}	1.94×10^{-4}	3.61×10^{-4}
Cr	1.10×10^{-8}	1.10×10^{-8}	1.40×10^{-8}
tHg	1.00×10^{-5}	3.33×10^{-5}	BDL

Note. BDL = Below detection limit.

Table 9. Hazard Quotient for Children via Ingestion Pathway

Heavy metal	Freshwater	Brackish water	Marine water
Cu	7.50×10^{-6}	7.50×10^{-6}	5.00×10^{-6}
Ni	5.56×10^{-5}	8.33×10^{-5}	1.39×10^{-4}
Cr	4.00×10^{-9}	4.00×10^{-9}	5.00×10^{-9}
tHg	3.33×10^{-6}	1.33×10^{-5}	BDL

Note. BDL = Below detection limit.

For both adults and children, all HQ ingestion values are very low, as shown in Tables 8-9. Ni is still producing the highest ingestion HQ, especially in the marine station, followed by Cu, but now in brackish water. Cr and tHg HQs are negligible as they are at such a very low value. Suggesting that all heavy metals are well below the HQs RFD, meaning that ingestion of river water for either group does not pose a significant hazard.

Table 10. Hazard Quotient for Adult via Dermal Absorption Pathway

Heavy metal	Freshwater	Brackish water	Marine water
Cu	3.73×10^{-3}	4.04×10^{-3}	2.38×10^{-3}
Ni	6.57×10^{-2}	7.43×10^{-2}	1.35×10^{-1}
Cr	0	0	0
tHg	2.22×10^{-4}	1.11×10^{-4}	BDL

Note. BDL = Below detection limit.

Table 11. Hazard Quotient for Children via Dermal Absorption Pathway

Heavy metal	Freshwater	Brackish water	Marine water
Cu	4.26×10^{-3}	4.60×10^{-3}	2.71×10^{-3}
Ni	7.49×10^{-2}	8.46×10^{-2}	1.54×10^{-1}
Cr	7.00×10^{-10}	7.00×10^{-10}	9.00×10^{-10}
tHg	2.22×10^{-4}	1.11×10^{-4}	BDL

Note. BDL = Below detection limit.

For Dermal absorption, it shows a higher HQ than ingestion due to the surface area, shown in Tables 10-11 (Exposure Assessment Tools by Routes - Dermal | US EPA, 2025). For adults, Ni is still the highest, especially in the marine station, with Cu still being the second highest in brackish water. Cr and tHg are still extremely small values compared to the parameter given. For children, on the other hand, it's higher than that of the adults due to their greater skin surface area-to-body-weight ratio (Yun et al., 2022). Even so, children having a higher dermal HQ all calculated dermal HQs for both age groups and both pathways are much less than 1.0, indicating that non-carcinogenic risks are currently low and negligible by the U.S EPA guidance, which are unlikely to cause adverse effects.

Hazard Index

The third step of HHRA also includes HI, the combined HQ to show that people affected aren't just absorbing or ingesting one contaminant, but multiple contaminants. Table 12 below shows the measured HI values for the Agusan River at the three sampling stations in freshwater, brackish water, and marine water, and two exposure pathways. By their parameters, an HI ≤ 1 is considered an acceptable value, whereas an HI > 1 indicates a potential concern.

Table 12. Hazard Index for Ingestion and Dermal Absorption across all Age Groups

Heavy metal	Freshwater	Brackish wate	Marine water
Adult via Ingestion	2.60×10^{-6}	2.70×10^{-6}	3.20×10^{-6}
Children via Ingestion	1.00×10^{-6}	1.00×10^{-6}	1.20×10^{-6}
Adult via Dermal Absorption	3.56×10^{-6}	3.74×10^{-6}	4.47×10^{-6}
Children via Dermal Absorptio	7.93×10^{-2}	8.93×10^{-2}	1.56×10^{-1}

For ingestion, it can be seen having HI for both adults and children in extremely low values. Being the largest ingestion, HI is only 0.00037 in adults in the marine water. This means all of the ingestion is well below 1, which indicates a negligible non-carcinogenic risk. While dermal exposure shows higher HI values than ingestion, it is still all well below 1. Being the highest dermal HI is 0.156 for a child at the marine water, so according to the U.S. EPA, it still remains a negligible non-carcinogenic risk. Having both negligible, which does not pose a significant health risk.

Cancer Risk

The third last step of HHRA is CR, which estimates the risk of developing cancer from a lifetime exposure to carcinogens. The study estimated the CR for Ni and Cr by the international standard U.S. EPA slope factors (Mariano, 2019). According to the U.S. EPA, risks below 0.000001 are considered negligible, and values above 0.0001 are unacceptable (TCEQ, 2024).

Table 13. Cancer Risk for Adult via Ingestion Pathway

Heavy metal	Freshwater	Brackish water	Marine water
Ni	5.00×10^{-9}	6.00×10^{-9}	1.10×10^{-8}
Cr	1.00×10^{-8}	9.00×10^{-9}	1.20×10^{-8}

Table 14. Cancer Risk for Children via Ingestion Pathway

Heavy metal	Freshwater	Brackish water	Marine water
Ni	2.00×10^{-9}	2.00×10^{-9}	4.00×10^{-9}
Cr	4.00×10^{-9}	4.00×10^{-9}	5.00×10^{-9}

Table 15. Cancer Risk for Adult via Dermal Absorption Pathway

Heavy metal	Freshwater	Brackish water	Marine water
Ni	2.93×10^{-7}	3.31×10^{-7}	6.02×10^{-7}
Cr	5.26×10^{-7}	5.20×10^{-7}	6.67×10^{-7}

Table 16. Cancer Risk for Children via Dermal Absorption Pathway

Heavy metal	Freshwater	Brackish water	Marine water
Ni	3.338×10^{-7}	3.774×10^{-7}	6.856×10^{-7}
Cr	5.99×10^{-7}	5.92×10^{-7}	7.59×10^{-7}

The findings indicate that Cr has a higher carcinogenic risk than Ni in the Agusan River, especially through dermal exposure. Being the highest values are in the marine water station and peaked at 0.000000759 in children; even so, these values are still well below the indicated limits by the Rfd, which is 0.0001. Meaning these values do not indicate a carcinogenic risk and are negligible.

The findings and results of the HHRA indicate that during the Hazard Identification part, it was seen that the heavy metal concentration exceeded the standards established in DAO No. 2016-08, even so the next part, which is the exposure assessment and risk characterization showed that the CDI, HQ, HI, and CR values are well below the established parameters by the U.S. EPA meaning that it does not pose either non-carcinogenic health risk or cargcinogenic health risk. Despite these findings, the data itself also showed specific areas that need to be monitored, as the highest concentrations of heavy metals were located mostly at the marine water station, and it was also found that children were found to be more vulnerable to exposure, given the higher values compared to the adults. Among the contaminants in this study, Ni and Cu showed the highest non-carcinogenic values, while Cr had the highest carcinogenic risk. Given the constant pollution of these heavy metals and the probability of them bioaccumulating, these values still need to be monitored to prevent long term issues in the future.

CONCLUSIONS

This study utilized and applied the HHRA of heavy metals by the U.S. EPA guidance. Specifically, Cu, Ni, THg, and Cr in the Agusan River, utilizing secondary data from Cabuga et al. (2019). The process focused on two exposure pathways, which are ingestion and dermal absorption, for both non-carcinogenic risk and carcinogenic risk for adults and children. During the hazard identification part, it was shown that heavy metals exceeded the standards established in DAO No. 2016-08. Even so, the next parts, exposure assessment and risk characterization shows that CDI, HQ, HI, and CR are well below the parameters by the U.S. EPA guidance. Meaning it does not pose a significant risk for both non-carcinogenic risk and carcinogenic risk. The study itself showed that among the metals studied, Ni and Cu had the highest values for non-carcinogenic risk, while CR had the highest potential for carcinogenic risk. The data also showed that the highest concentrations of heavy metals are largely located at the marine water station, and that children had higher vulnerability to these contaminants than adults themselves.

From the secondary data that we used, this study showcases an internationally standardized method for turning raw river contamination data into something clear, usable human-health risk assessment. By utilizing and applying a step-by-step process to evaluate the exposure given and identify what specific risk areas need to be monitored, it provides well-readable and easily compared results to different communities. Meaning that this study not only identifies the important parts that need to be evaluated and what areas need to be improved, but also, because this method follows a constant and easy process, it can serve as an important tool for researchers, government, and local groups. It has been shown that using standardized guidelines can be applied not only to the Agusan River, but also to many other river systems that need to be assessed to turn those raw numerical data into useful information to be used whether to find what areas need to be monitored or what needs to be improved more. While the current risks showed low probability to pose a significant risk, it is still necessary to be monitored because these heavy metals have the potential to bioaccumulate, so continued safety and development of solutions are recommended.

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