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EVALUATING ENVIRONMENTAL AND HUMAN HEALTH IMPACTS OF MINING

A Holistic Approach to Heavy Metal Contamination Assessment and the Development of a Rationality-Based Mining Decision Support through Cost-Benefit Analysis in Santa Cruz, Philippines

DR. PRINCE EDIKE
ORCID ID: 0009-0002-9351-7158
Strategic Integrated Solutions Industrial Design Services (SISIDS)
Sirib Center of Incubation, Saint Louis University Baguio City Philippines
britprinx@gmail.com

MR. PHILIP CAMARA
St. Augustine Sambali Fund, Inc. Vincente Camara Bldg.,
Sambali Center Zone V, Iba Zambales Philippines
philipcamara@gmail.com

ABSTRACT

A comprehensive ecological and human health risk assessment of heavy metal contamination resulting from nickel and chromite mining activities in Santa Cruz, Zambales, Philippines are hereby presented in this study. Contaminants including cadmium, chromium, cobalt, iron, lead, and nickel were analyzed in various ecosystem compartments, such as rice field soil, dust particles, and rice grains. The risk assessment revealed elevated concentrations of heavy metals, posing potential threats to both environmental health and human well-being. The rice field soil samples exhibited varying concentrations of heavy metals, with Rice Field Soil L2 showing particularly high levels of cadmium, chromium, and iron. More also, the dust particles analyzed show distinctive contamination patterns across locations, indicating the influence of different

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mining sites on heavy metal dispersion. Guiguis L1 and SC Dust L2 stood out with significant concentrations of several metals. Similarly, the composite Rice Grains L1 displayed notable concentrations of chromium, iron, and nickel.

The hazard Index (HI) values suggested a heightened risk of non-cancer health issues, especially in areas with high dust deposition, while the Cumulative Cancer Risk (CCR) values indicated an astronomical increased risk of cancer, emphasizing the potential long-term health implications of heavy metal exposure in the locality. On implementing the Pearson's Correlation, the correlation analysis revealed strong positive correlations between certain metals, signifying potential common sources with Nickel and chromium displaying a particularly noteworthy associations. Hence, we propose a Rationality-Based Mining Decision Support Model which utilizes Cost-Benefit Analysis (CBA). It is argued that this novel CBA model should integrate environmental, health, and economic data; wherein the costs associated with contamination remediation, health treatments, and ecosystem services valuation, providing a holistic approach for informed decision-making amid the current dependency on mining proceeds alone in proposing mining projects in the locality and the entire Philippines.

1.0 INTRODUCTION

In Santa Cruz, Zambales, the relentless expansion of mining operations, coupled with lax regulations and insufficient monitoring, has raised profound concerns regarding the health and environmental well-being of the local community. This is particularly alarming given the discernible enrichment of heavy metals in critical ecosystems, including farm soil, surface water, deposited dust from roadsides, and rice grains. Heavy metals, recognized carcinogens such as lead, cadmium, and arsenic, pose severe health risks in mining sites (Hagnazar et al., 2023; Nolos et al., 2022; Ngole-Jeme & Fantke, 2017; Ali et al., 2021; Bouida et al., 2022; Docena et al., 2018; Hassaan et al., 2016; Kim et al., 2015). The uncontrolled release of mine tailings during flash floods, indiscriminate mining in protected areas, and the emission of dust from mine sites and hauling trucks exacerbate the release of heavy metals. The toxic, persistent, and bioaccumulative nature of these metals amplifies the detrimental effects on both human life and diverse ecosystems; (Hagnazar et al., 2023; Hassaan et al., 2016; Kim et al., 2015), highlighting a pressing environmental concern in mining regions of developing countries, including Santa Cruz in Zambales, necessitating urgent recognition and action, as exemplified in some of the most relevant and recent research from disturbed ecosystems from the works of (Fadlillah et al., 2023; Milena et al., 2020; Decena et al., 2018; Akoto & Anning, 2021; Hagnazar et al., 2023).

To begin with, the increasing dust from ore hauling trucks along major road networks, as reported by communities, is a matter of concern. The impact of airborne dust has been associated with both immediate and prolonged health repercussions in humans (Lara et al., 2021). Additionally, considerable epidemiological data substantiates its correlation with heightened daily morbidity and mortality rates (Huang et al., 2019). These observations underscore the multifaceted challenges arising from mining activities and emphasize the need for a thorough investigation into the ecological and human health risks associated with heavy metal contamination in Santa Cruz.

In response to these concerns, this research adopts a comprehensive approach to assess the ecological and human health risks linked to heavy metal contamination. The computation of the Potential Ecological Risk Index employs toxic response factors for each heavy metals, while the Contamination Factor, Pollution Load Index, and Enrichment Factor were dully computed to assess the metals impacts on the ecosystems as they each have their interpretations. The corresponding geochemical background concentrations were based on (Bowen, 1979; Turekian, 1961; Olivares et al., 2019). The human health risk assessment model follows guidelines from USEPA, 1989, through USEPA, 2004 to USEPA, 2011, with similar goals achieved in the following papers; (Lisa et al., 2021; Patil et al., 2022; Sin & Espuña, 2020; Lanzani et al., 2019; and Nduka et al., 2019). The computational analysis, implemented through the Python programming language using google colab and the aim is to provide a detailed understanding of the extent and nature of heavy metal contamination in Santa Cruz with line and bar plotting for visualization.

The research framework involves a comprehensive investigation into heavy metal contamination in Santa Cruz, Zambales, suspected to originate from mining activities. This encompasses the collection and analysis of samples from diverse ecosystem compartments, including farm soil, surface water, rice grains, and deposited dust particles as seen in figure 1. Similar work have been executed in mining communities through the sampling, analysis and reporting of the risk level from surface water; (Alcolea et al., 2015;), atmospheric deposited contaminates; (Yu et al., 2023; Wang et al., 2003;), soil, sediment and rice grain in e-waste dismantling center; (Li et al., 2021), groundwater; (Liu & Ma, 2020; Lu et al., 2016), rice grains, stem and leaves due to bioaccumulation from contaminated soil (Gu et al., 2018), soil and water media (Ahmad et al., 2021). Interestingly, the high correlation between contaminated soil to crop and the need for risk assessment on this due-ecological compartment has been documented (Mingtao et al., 2021), contaminated soil from coal mining and production sites; (Zhang et al., 2021), and the need for more holistic approach to risk assessment involving the uncertainty considerations, bioavailability, sensitivity analysis and robust modeling of risk to capture the dynamics of stressed ecosystems (Panquin et al., 2023; Yang et al., 2023). These processes include the application of environmental indices (PERI, CF, PLI, Igeo, EF) for ecological risk assessment, statistical analyses for spatial patterns, and health risk modeling for human exposure assessment. The output aims to deliver a decision support model for cost-benefit analysis, integrating health, environmental, and economic data to quantify the costs associated with heavy metals contamination. This model will inform policy makers on sustainable management practices, offering a holistic perspective on the ecological risks and human health hazards posed by heavy metals in Santa Cruz and their origin.

Figure 1. Photos taken During the Sampling Exercise in Santa Cruz Zambales

The research principal objective is to conduct a comprehensive heavy metals risk assessment in Santa Cruz, Zambales, with a focus on quantifying, evaluating the extent and impact of heavy metals contamination suspected to originate from mining activities. The research aims to provide insights into the potential ecological risks and human health hazards associated with heavy metals in different ecosystem compartments, facilitating informed decision-making and sustainable management practices.

To satisfy the above main objective, here are the steps taken; 1) To sample, analyze, quantify and determine the spatial distribution of heavy metals in farm soil where rice are planted regularly, surface water from the major river systems, rice grains, and deposited dust particles from the major road networks across Santa Cruz, Zambales, aiming to identify hotspots and understand the spatial patterns of contamination. 2) Conduct ecological risk assessment using different environmental indices: Apply relevant environmental indices such as Potential Ecological Risk Index (RI), Contamination Factor (CF), Pollution Load Index (PLI), and Enrichment Factor (EF) to assess and categorize the ecological risks posed by heavy metals in each ecosystem compartment. 3) Evaluate human health risks associated with heavy metals exposure: Estimate human health risks by assessing exposure pathways and applying established models to link heavy metal concentrations in environmental compartments to potential health outcomes, focusing on local communities. 3) Utilize statistical Pearson’s correlation to identify spatial patterns, correlations, and potential sources of heavy metals contamination across different sampling points. 4) Develop a Rationality-Based Mining Decision Support Model through Cost-Benefit Analysis: Create a comprehensive model integrating health, environmental, and economic data to quantify the costs associated with heavy metals contamination. This model should facilitate a cost-benefit analysis, considering both health impacts and the valuation of ecosystem services, to support informed decision-making for mining permits.

These steps were taken to provide a holistic understanding of heavy metals contamination in Santa Cruz, emphasizing the integration of ecological, human health, and economic perspectives for a comprehensive risk assessment and sustainable management strategy. The four steps entail the heavy metals risk assessment in Santa Cruz, Zambales, collectively form a holistic strategy to comprehensively understand and address the suspected heavy metals contamination originating from mining activities. Step one focuses on meticulously analyzing heavy metal concentrations in diverse environmental compartments, namely farm soil, surface water, rice grains, and deposited dust particles from various sampling points. Step two extends the assessment to ecological risks, employing established indices to categorize and quantify the potential harm posed by heavy metals across these ecosystems. Simultaneously, step three broadens the scope to human health risks, employing exposure pathway assessments and established models to connect heavy metal concentrations with potential health outcomes, particularly in local communities. Step four employs sophisticated statistical analyses to discern spatial patterns and potential contamination sources across the sampled points, ensuring a nuanced understanding of the dynamics of heavy metals in the environment. Together, these objectives aim to provide critical insights into the multifaceted dimensions of heavy metals contamination, enabling informed decision-making, sustainable management practices, and potential policy recommendations for safeguarding both the environment and public health in Santa Cruz.

Building on the results, the final step proposes a decision support model to enhance rational decision-making in the mining permitting process in the Philippines. This model integrates the opportunity cost from heavy metals contamination remediation, human cancer and non-cancer-related risk treatment linked to heavy metals contamination, and Ecosystem Services Valuation. By incorporating these factors into a holistic accounting system, the proposed Cost-Benefit Analysis of Mining in the Environmental Impact Assessment System aims to offer a more comprehensive and rational valuation framework for sustainable development in Santa Cruz Zambales' mining sector and could go a long way to revitalize the monitoring, management phases of the environmental impact assessment and a host of post assessment strategies for national policy change.

The proposed framework acknowledges the need for a balanced approach to mining projects, considering economic, ecological, and social dimensions. Through the integration of treatment costs, ecosystem services valuation, and the associated human health risks, decision-makers gain insights into the full spectrum of impacts associated with mining projects. This framework aligns with sustainable development goals, emphasizing the protection of the environment and local communities, and underscores the importance of a rational decision-making process that weighs potential positive and negative impacts of mining activities.

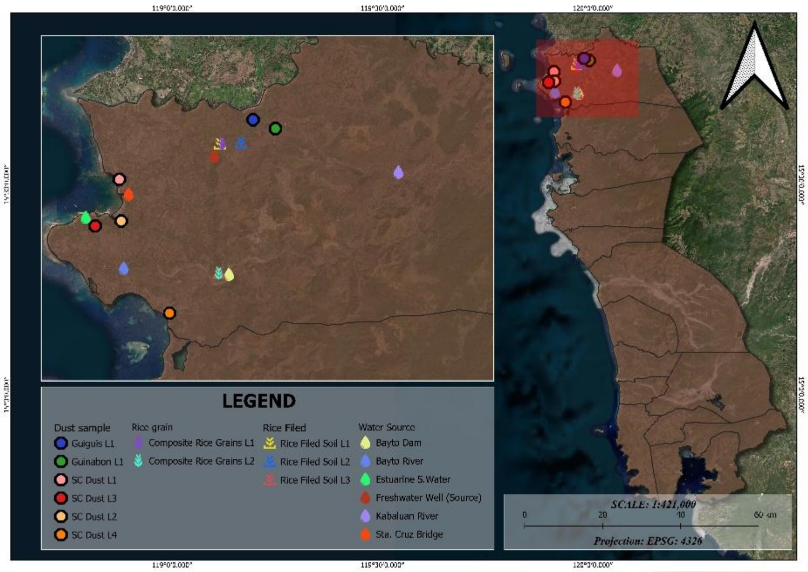

Figure 2. The Map of the Sampled Locations and Sample Types; Santa Cruz Zambales, Philippines.

The province of Zambales, located in the Central Luzon region of the Philippines, is known for its rich mineral resources, including nickel, chromite, and copper (Yumul, 1992). Mining activities in Zambales have increased in recent years, leading to concerns about the potential ecological impacts of these activities.

In response to the critical necessity for a comprehensive ecological risk assessment in areas affected by anthropogenic activities, this research is conducted as an integrated study; focusing on farm soil, dust particles, river water, and rice grains samples collected from spatially distributed sites in Santa Cruz, Zambales, impacted by mining activities. The urgency of such assessments has been underscored by studies like that of Decena et al. (2018) on Mangonbangon River, Tacloban City, which revealed moderate enrichment of Zn and Cu, emphasizing the potential ecological risks. Additionally, Domingo et al. (2023) provided essential insights into sediment source contributions and floodplain contamination in a nickel-mining-affected catchment in Santa Cruz, Zambales, highlighting the importance of proactive rehabilitation to mitigate broader environmental impacts in the locality.

To extend the scope, it is imperative to sample deposited dust in Santa Cruz to assess the risks associated with mining company hauling activities, given the established enrichment of trace elements in urban deposited dust from various sources, as demonstrated by Yang et al. (2020) and Zeng et al. (2021). Furthermore, drawing parallels with Li et al. (2023) and Lu et al. (2022), who assessed cultivated soil near mining sites, this research aims to explore the elevated risk of soil contamination by potentially toxic elements in areas characterized by both high geological background and intensive mining activities. This includes arsenic, mercury, copper, zinc, lead, cadmium, and chromium, posing threats to ecosystem safety and agricultural productivity, with implications for risk assessment studies in similar ophiolite complex areas like Santa Cruz, Zambales.

Risk assessment of heavy metals has been expanding in recent years with assessment of heavy metals' ecological risk from mining to e-waste dismantling (Li et al., 2021); here, despite the closure of informal e-waste dismantling centers in Longtang, China, heavy metals, notably Cu and Cd, remain major environmental concerns as their levels in sediments and soils pose high and considerable risks, particularly to human health, while the heavy metal content in rice grains, although within acceptable thresholds, necessitates continuous monitoring in Longtang contended by the authors. The ecological and human health risk assessment of heavy metals in dust towards restoration opportunities presented during the COVID-19 pandemic lockdown in Dhaka city has been considered (Rabin et al., 2023); here, the authors analyzed street dust samples from various areas, revealing higher concentrations of toxic elements during partial lockdown, predominantly sourced from anthropogenic activities. This underscores the need for comprehensive toxic element assessments for public health safety and ecological sustainability. Al-Swadi et al. (2022) investigated the sources and levels of heavy metals in soil and dust of urban and suburban areas in Riyadh and Mahad AD'Dahab, Saudi Arabia, emphasizing the higher contamination levels of heavy metals in dust compared to soil samples. Similarly, Osorio-Martinez et al. (2021) assessed the particle size distribution, composition, and environmental and human health risks of urban dust in Barranquilla, Colombia, revealing extreme contamination and emphasizing the need for educational programs and enhanced monitoring to safeguard environmental and human health against chronic exposure to toxic elements as argued by Heijden (2020).

Furthermore, Alghamdi et al. (2023) assessed sporting walkways in Jeddah, Saudi Arabia, documenting elevated concentrations of potentially toxic metals in deposited dust, posing risks for both children and adults. Additionally, Zeng et al. (2019) identified elevated levels of metal contaminants in drinking water from Shanzi Reservoir, China, revealing potential health risks and underscoring the need for targeted risk mitigation strategies. The comprehensive nature of this research aims to provide a decision support system that incorporates ecosystem services often overlooked in the pursuit of mining benefits, contributing to sustainable environmental management.

Kumar et al., (2022) conducted a comprehensive ecological risk assessment of heavy metals in soils and sediments across 17 countries, revealing the highest concentrations of Cd and

Hg in India and Poland, respectively, emphasizing the global significance of managing heavy metal contaminations, particularly in mining areas, to safeguard water and soil resources. More also, Liu et al., (2021) investigates heavy metal pollution in the Xihe River, China, using canonical correlation analysis, principal component analysis, and the potential ecological risk index, revealing significant contamination of As, Cd, Cu, Hg, and Zn primarily originating from industrial discharge in the upstream areas. The research emphasizes the importance of effective sewage discharge management for urban rivers, addressing global concerns about heavy metal pollution's environmental impact and the need for region-specific solutions, which is particularly relevant for the Philippines, given its mining activities and potential ecological vulnerabilities. Sampling crops in risk assessment study is critical in agriculture areas as argued in (Xiang et al., 2021); this underscores the often-neglected complexity of the relationship between soil and crop pollution, emphasizing the need for regional-scale studies. In the context of mining areas in the Philippines, such studies are crucial as heavy metal pollution threatens agricultural productivity, ecosystem health, and human well-being, emphasizing the necessity for comprehensive risk assessments.

Similarly, Hagnazar et al., (2023) conducted a comprehensive assessment of potentially toxic elements (PTEs), including arsenic, cobalt, chromium, copper, manganese, nickel, lead, and zinc, in the Zarjoub and Goharroud river basins in northern Iran which is a watershed similar to that of Santa Cruz Zambales, revealing moderate to heavy pollution and toxicity in the sediments of these two highly polluted rivers, with implications for the contamination of paddy soils and rice grains, ultimately posing significant ecological risks and potential health hazards for local inhabitants due to metal bioaccumulation, emphasizing the urgent need for effective policy change regarding mining in Santa Cruz Zambales and similar environments where heavy metal contamination is prevalent.

By accomplishing the outlined set of objectives in this research, we endeavor to construct a robust framework that provides decision-makers with a nuanced understanding of the economic trade-offs inherent in mining projects within Santa Cruz Zambales, Philippines. Our study acknowledges the substantial negative impacts on ecosystem services associated with ongoing mining activities, as extensively highlighted by Bodly et al. (2021). Although restorative efforts exhibit positive effects, the research underscores the considerable challenges in managing ecosystems in mining regions, emphasizing the necessity for a lucid identification of changes in the ecosystem services chain throughout the mining lifecycle.

The proposed research agenda thus aspires to fill these knowledge gaps, aiming to elevate ecosystem management practices for the betterment of both ecosystem services and human well-being in mining areas, in alignment with the insights put forth by Taylor & Bennett (2016). Moreover, the work aligns with the perspective advocated by Dendoncker et al. (2013), emphasizing the adoption of a comprehensive ecosystem services valuation approach that extends beyond purely monetary considerations, incorporating ecological and social values. This approach is particularly relevant in the context of Santa Cruz Zambales. The authors advocate for a strong sustainability perspective that prioritizes the well-being of individuals and societies in the present and future alike.

The valuation process, as suggested, should adopt a systemic approach, considering bundles of ecosystem services concurrently. The proposal contends that, in situations where systems are not at critical thresholds, valuing changes through alternative options is suitable, leveraging deliberative multicriteria decision tools to facilitate collective valuation. Conversely, when systems are on the brink of tipping points, the focus should pivot from comparing resources or alternatives to valuing the prevention of catastrophic ecosystem change. It is crucial to recognize that valuation alone cannot provide a complete solution; political, governance, and institutional factors play indispensable roles in realizing sustainability objectives.

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Ecosystem services are natural processes or attributes of ecosystems that yield measurable economic benefits to humans, with varying definitions and applications. The concept of ecosystem services has gained prominence alongside market-based environmental management policies, encompassing diverse phenomena such as pollination, water quality provision, climate change mitigation, and aesthetic amenity (Robertson, 2011). The urgent need to assess the ecosystem services in project sites was documented (Schuster & Doerr, 2015) and particularly areas prone to mining operations (Mercado-Garcia et al., 2018); the later authors highlight the need for methodological consensus and a policy-oriented framework to enable holistic assessments of mining impacts, emphasizing the importance of considering data constraints, social-ecological connectivity, and cause-effect networks in environmental modelling for analyzing mining impacts. Schuster & Doerr, 2015 elaborated that by conducting ecosystem service valuation studies, an enhancement of project design, management, and garner greater stakeholder support and funding could be realized, ultimately leading to increased project success and the simultaneous promotion of both human and natural well-being.

In consistence with the World Economic Forum push to adopt the concept of Gross Ecosystem Product (GEP); developed to measure and aggregate the economic value of different ecosystem assets by translating their biophysical value into monetary terms. GEP, modeled after Gross Domestic Product (GDP), uses market prices and non-market valuation techniques to calculate the accounting value of ecosystem goods and services. It allows for a better understanding of nature's contribution to human well-being and can serve as an indicator of the extent and quality of ecosystems, providing valuable information for decision-making and development planning. This concept allows for instance, the ecosystem services in Zamabales to be considered holistically in terms of their economic values and not just limiting the economy of the locality to have a growth trajectory from mining alone.

The task of evaluating ecosystem services and potential risk in monetary terms concerning mining benefits might seem intricate, but established tools, methods, and data sources have been widely utilized in global research efforts (Fazekas, 2019; Markandya, 2019; Robertson, 2011; Liekens et al., 2013; Dendoncker et al., 2013). We propose the application of market-based valuation and multicriteria decision analysis as pivotal tools directly integrated into our computational model. In market-based valuation, the approach involves utilizing market prices or proxy markets to estimate the value of ecosystem services, with examples including landscape valuation based on real estate pricing and estimating the value of clean water by examining water prices in nearby markets. Relevant data for this method could be sourced from local market data, government reports, hospital bills, commodity exchanges, and trade associations. The analysis entails comparing market prices of ecosystem services to mining-generated revenue to assess their relative importance and economic trade-offs.

On the other hand, the use of multicriteria decision analysis allows for a comprehensive decision-making framework, incorporating multiple indicators such as economic benefits, ecosystem health, social well-being, and sustainability goals (Markandya, 2019; Dendoncker et al., 2013). Data and parameters supporting this model would be derived from multiple indicators across economic, ecological, and social domains, including stakeholder preferences and weights assigned to different criteria.

2.0 MATERIALS AND METHOD

1. Selection of Sampling Points: The identification of representative sites was done through the utilization of GPS and compass; the stations coordinates were chosen based on suspected mining activities, environmental variability, and proximity to areas were complaints were made as well as the pristine areas. The inclusion of complaint sites were incorporated as sites with documented

complaints related to environmental issues and areas without complaints. Moreover, to ensure representation over farm lots, rivers, and road networks, spatial distribution of the sites were considered using QGIS software for a comprehensive geospatial assessment. This integrated approach provides a holistic understanding of the spatial patterns and potential risks associated with heavy metal contamination in different environmental compartments.

2. The soil sampling and collection tool employed is an auger for soil probing and sample collection depth over 30cm for all sites however, the collection of soil samples at various depths not more than 30cm to capture potential variations in heavy metal concentrations was implemented and each stations points sample homogenized and then placed samples in dry, sealed plastic containers to prevent contamination.

3. Surface water sampling collection was achieved through the gathering and fetching of the surface water samples from flowing rivers at a depth of 0.5 to 1 meter from the surface, then samples were stored in sealed containers to maintain integrity during transportation.

4. Rice grain sampling were obtained from sampled rice fields. The samples were prepared through pulverization into powdered form using a mortar and pestle, the powdered rice samples were sealed in containers for further analysis.

5. Deposited dust particle sampling was conducted from the selected sites along major road networks using brushes to remove samples from leaves, abandoned parked vehicles, and road surfaces considering potential heavy metals deposition sources from the trucks carrying the ore extracted from the different mining sites to the ports for export. The collected dust particles ranging from 1 to 75 µm in diameter. The sieve analysis was conducted at the Central Luzon State University Science City of Munoz, Nueva Ecija, to ensure the uniformity and quality of the 75 µm fraction.

6. The laboratory analysis was conducted using all the collected samples at the CRL Environmental Corporation in Clarkfield, Pampanga, where the sample were prepared and analyzed. The ICP-MS (Inductively Coupled Plasma Mass Spectrometry) or ICP-OES (Inductively Coupled Plasma Optical Emission Spectrometry) for accurate and precise heavy metals analysis was utilized for the heavy metals analysis.

8. Data Processing and Statistical Analyses: The compiled and organized data obtained from the laboratory analysis was implemented to be computationally analyzed and modeled using the various ecological risk assessment indices, the potential human health risk assessment, Monte Carlo Simulations for the non-deterministic outcomes, and the statistical method through the application of the Pearson's correlation for data interpretation. The experimental semivariogram, a graphical representation of spatial autocorrelation, was employed to assess the spatial dependence of heavy metal concentrations measured at diverse sampling points. Analyzing the variance (semivariogram) as a function of distance lag (separation distance) reveals the spatial structure and interrelationships between metal concentrations (Oliver & Webster, 1992). This information serves as the basis for kriging, a geostatistical method used to construct a spatial model and interpolate values at un-sampled locations based on the weighted relationships between known points (Mosammam, 2013). The resulting kriged map provides a spatially continuous representation of heavy metal concentrations, extending beyond the sampled points with estimated precision and uncertainty (Hohn, 1991). The visualizing the heavy metal contamination's spatial distribution in the studied area would systematically aids in contamination tracking (Milena et al., 2020). Hence, we implemented geostatistical interpolation, semi-variagram and kriging methods; which enable us to obtain information for areas within Santa Cruz that are unaccessible and also to limit our sampling locations due to budget constraints. Spatial visualization is extensively used in soil heavy metals risk assessment research (Milena et al., 2020; Cheng et al., 2020; Jiang et al., 2020; Ebtessam et al., 2022). As exemplified in the

work of Panquin et al., (2023); and Yu et al., (2023); we also implemented Monet Carlo Simulation to predict the contaminants spatial distributions through consideration of the variability and uncertainty in variables utilized.

9. By employing python programming, we utilized statistical and machine learning libraries (pandas, and scikit-learn) to develop a decision support model integrating health, environmental, and economic data, facilitating a cost-benefit analysis for the heavy metals risk assessment in Santa Cruz, Zambales.

This comprehensive methodology integrates robust sampling techniques with precise laboratory analyses and statistical methodologies, ensuring a thorough assessment of heavy metals contamination in Santa Cruz, Zambales. The methodology prioritizes quality assurance, representation of various environmental compartments, and adherence to standard sampling and analysis protocols.

Figure 3. Photos Taken During the Laboratory Exercise at CRL Environmental Corporation

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2.1 Ecological Risk Assessment Models and Indices Utilized

i) Potential Ecological Risk Index (PERI) = $\sum(Ei * Ti)$

Where Ei is the ecological risk factor and Ti is the toxic-response factor for each metal

Higher PERI values indicate a higher potential ecological risk. PERI below 150: Low ecological risk.

PERI between 150 and 300: Moderate ecological risk. PERI exceeding 300: High ecological risk; (Hakanson, 1980).

ii) Contamination Factor (CF) = Cmetal in sample / Cbackground metal
CF values greater than 1 indicate contamination above the background level.
CF values less than or equal to 1 suggest no significant contamination compared to the background. Higher CF values indicate a higher degree of contamination.

iii) Pollution Load Index (PLI) = $(n\sqrt{}(B1 * B2 * ... * Bn)) / (n\sqrt{}(C1 * C2 * ... * Cn))$

Where Ci is the concentration of the metal in the sample and Bi is the background concentration of the metal. PLI values greater than 1 indicate the presence of multiple contaminants and potential pollution, while the PLI values less than or equal to 1 suggest no significant pollution.

iv) Enrichment Factor (EF): A measure of the degree to which a heavy metal concentration is enriched in a sample compared to a reference element, often used to distinguish between natural and anthropogenic sources of metals.

Formula: EF = (C_m / C_{ref}) sample / (Cm / C_{ref}) background

Where: C_m is the measured concentration of the metal and C_{ref} is the measured concentration of the reference element (e.g., Fe). Here's how the Enrichment Factor is generally interpreted:

EF < 1: Depletion or no enrichment, hence, the concentration of the metal in the sample is lower than or equal to its background or reference concentration. This suggests that there is no significant enrichment of the metal and may indicate that the metal is at a natural or background level. 1 < EF < 2: Minimum enrichment. Hence, the concentration of the metal in the sample is moderately higher than its background or reference concentration, but the enrichment is considered minimal. 2 < EF < 5: Medium enrichment, hence the level of the metal in the sample is moderately to significantly higher than its background or reference concentration, indicating a medium level of enrichment. 5 < EF < 20: Adequate enrichment, meaning the concentration or level of the metal in the sample is significantly higher than its background or reference concentration, indicating a substantial level of enrichment. 20 < EF < 40 denote a high enrichment, meaning that the level of concentration of the metal in the sample is highly enriched compared to its background or reference concentration, suggesting a high level of enrichment. EF > 40: hence, the very high enrichment. Which means that the concentration of the metal in the sample is extremely high compared to its background or reference concentration, indicating a very high level of enrichment. In summary, the Enrichment Factor provides a quantitative measure of the extent to which a metal is enriched in a sample compared to its natural or background levels. Higher EF values indicate a higher degree of enrichment, and this information is crucial for understanding the sources and potential environmental impact of metal contamination. It is commonly used in environmental studies, especially in the assessment of heavy metal pollution in soil or sediment.

2.2 Potential Human Health Risk Assessment Model

Daily Intake (CDI) Formulas:

i) Inhalation exposure calculations

$CD_{In} = (C_{air} * IR * EF * ED) / (PEF * BW * AT_{nc})$

$HQ = CD_{Inc} / RfD$

ii) Dermal exposure calculations

$CDI_d = (C_{soil} * SA * AF * IR * ABS * EF * ED) / (BW * AT_{nc})$

$HQd = CDId / RfD$

iii) Oral exposure calculations

$CDI_{oral} = (C_{soil} * IR * EF * ED) / (BW * AT_{nc})$

$HQoral = CDI_{oral} / RfD$

Hazard Index (HI)

$HI = HQ + HQ_d + HQ_{oral}$

Cumulative cancer risk (CCR) calculations for each pathway

$CDI_c\_inhalation = (C_{air} * IR * EF * ED) / (PEF * BW * AT_c)$

$CDI_c\_dermal = (C_{soil} * SA * AF * IR * ABS * EF * ED) / (BW * AT_c)$

$CDI_c\_oral = (C_{soil} * IR * EF * ED) / (BW * AT_c)$

$TCR\_inhalation = CDI_c\_inhalation * CSF$

TCR_dermal = CDI_c_dermal * CSF

TCR_oral = CDI_c_oral * CSF

Total Cumulative Cancer Risk (CCR) across all pathways

TCR_total = TCR_inhalation + TCR_dermal + TCR_oral

Note:

CDI_n is the chronic daily intake through inhalation (mg/kg/day)

C_{air} is the concentration of the contaminant in air (mg/m^3)

IR is the inhalation rate (m^3/day)

EF is the exposure frequency (days/year)

ED is the exposure duration (years)

PEF is the soil to air particulate emission factor (m^3/kg)

BW is the body weight of the adult individual (kg)

AT_{nc} is the averaging time for non-carcinogenic effects (days)

AT_c is the averaging time for carcinogenic effects (days)

CDI_d is the chronic daily intake through dermal contact (mg/kg/day)

C_{soil} is the concentration of the contaminant in soil (mg/kg)

SA is the skin surface area in contact with soil (cm^2/event)

AF is the soil adherence factor (mg/cm^2/event)

ABS is the dermal absorption fraction (unitless)

RfD is the reference dose for each metal (mg/kg/day)

CSF is the cancer slope factor for each metal ($(mg/kg/day)^{-1}$)

(USAEPA, 1989; USAEPA, 1997; USAEPA, 2011; and USDOE, 2011, Finley et al., 2012)

3.0 DATA PRESENTATION AND DISCUSSIONS

3.1 Data Presentation

To satisfy the first objective, the spatial distribution of heavy metals in farm soil where rice are planted regularly, surface water from the major river systems, rice grains, and deposited dust particles from the major road networks across Santa Cruz, Zambales are analysed from the Appendix A. The table in APPENDIX A shows the results of heavy metal analysis in different environmental samples collected with the dust samples show high levels of Cr, Co, Fe, and Ni, indicating that these metals are present in the air as particulate matter. The dust samples from Guiguis L1 and SC Dust L2 have the highest concentrations of Cr (184,000 mg/kg and 95,600 mg/kg, respectively), which is a known carcinogen and can cause respiratory problems. The dust samples from Guinabon L1 and SC Dust L4 have the highest concentrations of Co (68,100 mg/kg and 69,400 mg/kg, respectively), which can cause skin irritation and allergic reactions. The dust samples from Guiguis L1 and SC Dust L3 have the highest concentrations of Fe (7,230 mg/kg and

4,180 mg/kg, respectively), which can cause oxidative stress and tissue damage. The dust samples from SC Dust L1 and SC Dust L2 have the highest concentrations of Ni (4,700 mg/kg and 4,800 mg/kg, respectively), which can cause dermatitis and lung inflammation. The dust samples also have low to moderate levels of As, Cd, and Pb, which are toxic metals that can affect the nervous system, kidneys, liver, and blood.

The rice grain samples show low levels of Cr, Co, Fe, and Ni, indicating that these metals are not readily taken up by the rice plants. The rice grain samples have no detectable levels of As, Cd, and Pb, which is a good sign for food safety.

The rice farm soil samples show moderate to high levels of Cr, Co, Fe, and Ni, indicating that these metals are present in the soil and can affect the soil quality and fertility. The rice farm soil samples from Rice Filed Soil L1 and Rice Filed Soil L2 have the highest concentrations of Cr (2,480 mg/kg and 2,450 mg/kg, respectively), Co (175 mg/kg and 173 mg/kg, respectively), Fe (141,000 mg/kg and 132,000 mg/kg, respectively), and Ni (4,840 mg/kg and 4,910 mg/kg, respectively). These levels are much higher than the background levels of these metals in Philippine soils, which range from 10 to 100 mg/kg for Cr, 5 to 50 mg/kg for Co, 10,000 to 50,000 mg/kg for Fe, and 5 to 500 mg/kg for Ni. The rice farm soil samples also have low to moderate levels of Cd and Pb, which can affect the plant growth and yield. The rice farm soil samples have no detectable levels of As, which is a positive sign for soil health.

The surface water samples show low to high levels of Cr, Co, Fe, and Ni, indicating that these metals are present in the water and can affect the water quality and aquatic life. The surface water samples from Estuarine S. Water and Bayto River have the highest concentrations of Cr (27 mg/L and 66 mg/L, respectively), Co (27 mg/L and 66 mg/L, respectively), Fe (1 mg/L and 3 mg/L, respectively), and Ni (1 mg/L and 3 mg/L, respectively). These levels exceed the DENR water quality guidelines for most classes of water bodies, except for class D (agricultural

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water supply) and class SD (industrial water supply). The surface water samples also have low levels of As, Cd, and Pb, which are below the DENR water quality guidelines for all classes of water bodies.

3.2 Spatial Interpretation of Contamination and Trend of the Deposited Dust Particles

Understanding the spatial patterns of contamination would lead to the identification of the contamination hotspots. Contamination hotspots are areas with elevated concentrations of heavy metals, indicating potential environmental risks and health hazards.

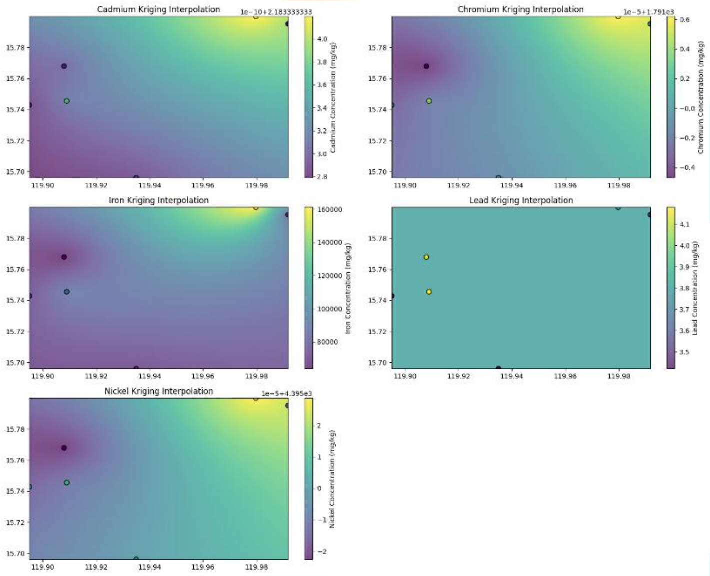


Figure 4. OrdinaryKriging Interpolation plot of the deposited dust particles samples across multiple locations in Santa Cruz Zambales.

One possible explanation for these patterns is that there is a mining company or a group of mining companies operating not far from Guiguis L1 and Guinabon L1, which are the main sources of contamination for all metals except Lead (Pb) which may have been released from the vehicles from the town proper with the highest concentration at SC Dust L2 and lowest at SC Dust L4. The concentration remained homogenous, with some local variations unlike the rest heavy metals which shows similar trend and pattern i.e., Cd, Cr, and Ni highest at Guiguis L1 and lowest at SC Dust L1, while Fe is highest at Guinabon L1 lowest at SC Dust L1 and the concentration decreases from east to west and from north to south as seen in figure 4, with some local variations. This trend followed the direction of the mining companies operating in Santa Cruz Zambales location and trucking movement to the ports i.e, from the mountains on the eastern Santa Cruz to the ports on the West Philippines Sea. Hence, these metals could have been released into the environment by mining activities, carried by water or wind to other locations, creating a concentration gradient as seen in the interpolation map and semiverogram plotting in figure 5. The metals could also be transported by hauling trucks that ply the road between Guiguis L1 and Guinabon L1, creating dust and emissions that could contaminate the air and soil. The spatial dependence of the metals could reflect the intensity and frequency of the contamination sources, as well as the natural variability of the terrain and the environmental factors**.**

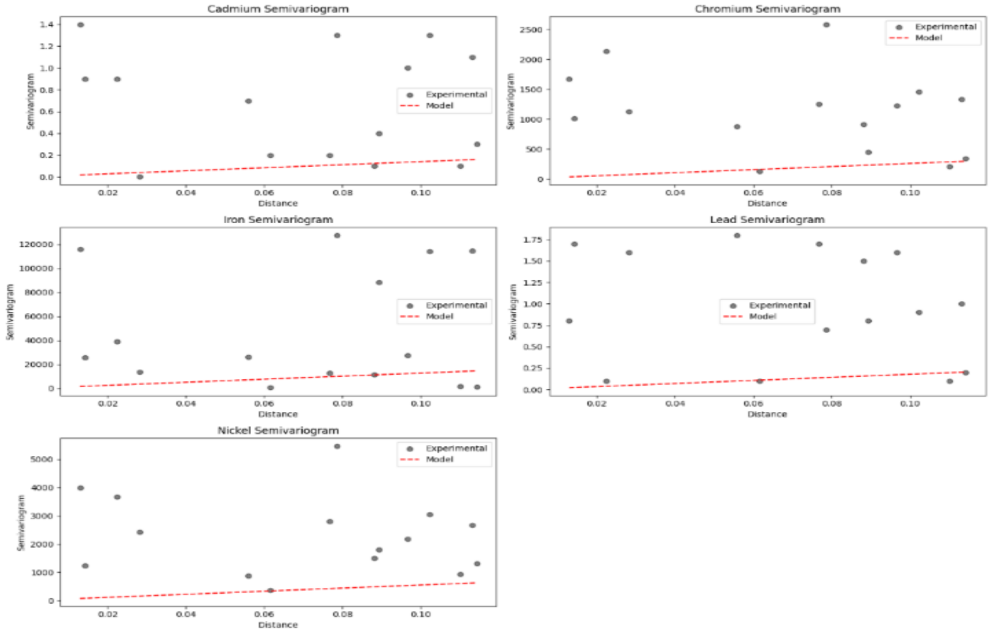


Figure 5. The Semiverogram plots of all the samples locations and their heavy metals concentration values in response to spatial autocorrelation.

The semivariogram results show how the spatial autocorrelation of the metal concentrations changes with distance. The semivariogram has three main parameters: the nugget, the sill, and the range. The nugget represents the variability at very short distances, the sill represents the maximum semivariance at large distances, and the range represents the distance at which the semivariance reaches the sill. The semivariogram results for each metal are different, indicating different spatial patterns and sources of contamination. Cadmium and Lead have low nuggets, sills, and ranges (0.2, 0.8 and 0.01; 0.2, 1.2 and 0.02) respectively, meaning that they have low variability and weak spatial dependence indicating a general source or background values with possibility of the vehicles and local geochemical background being the source of the two metals. Chromium, Iron, and Nickel have high nuggets, sills, and ranges, (50000, 3000000 and 0.01; 500000, 20000000 and 0.01; 100000, 6000000 and 0.01) respectively as seen in the figure 5, indicating that they have high variability and strong spatial dependence, hence, Cadmium and Lead are more dispersed and homogeneous, while Chromium, Iron, and Nickel are more clustered and heterogeneous much the same as what mining footprint would yield in a mountainous landscape having pockets of mining activities and the dust from the hauling trucks moving around and stationing in certain areas for refueling and unloading.

3.3 Spatial Interpretation of Contamination and Trend of the Rice Field Soil Samples

The interpolation trend indicates that the concentration of each metal varies spatially, with some areas having higher or lower values than others. For example, Cadmium, Iron, Chromium and Nickel have the lowest concentration in the southwest corner as seen in figure 6a and 6b. The semivariogram results indicate that the spatial correlation of each metal decreases as the distance increases, meaning that the metal concentration is more similar between nearby locations than between distant locations. The semivariogram also shows the nugget, sill, and range values for each metal, which reflect the local variability, the overall variance, and the characteristic spatial scale of the data, respectively.

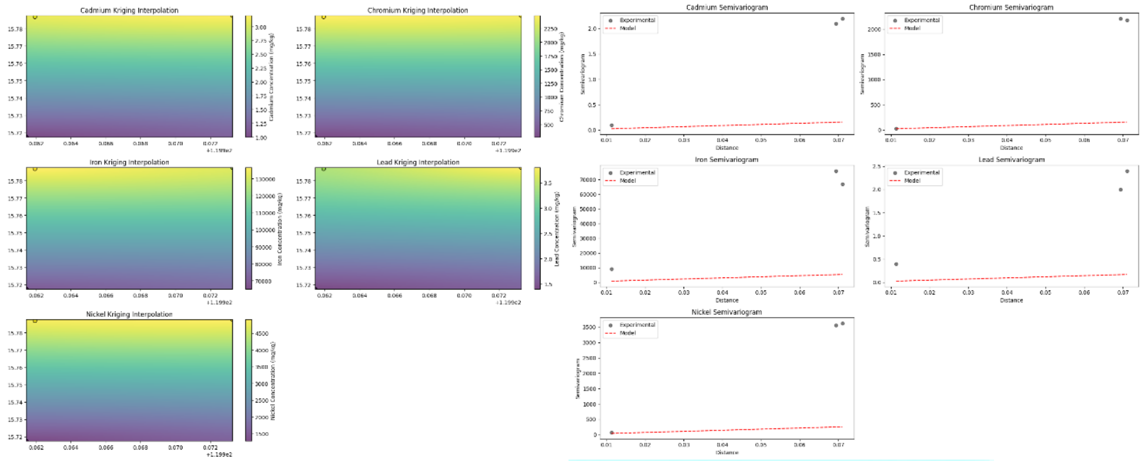


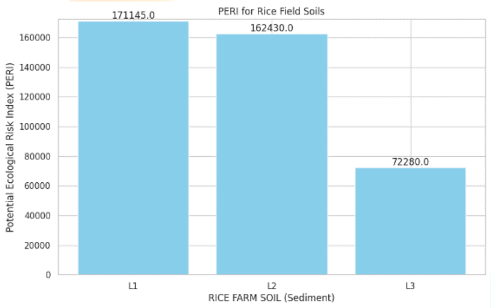
Figure 6a: The interpolation trend of the heavy metals analyzed from rice field soil obtained from three farms in Santa Cruz Zambales. 6b: The semivariogram plot showing the nugget, sill, and range values for each metal, which reflect the local variability, the overall variance, and the characteristic spatial scale of the data, respectively.

Chromium and Nickel have relatively high sill values, indicating that there is a large variation in the metal concentration across the area. Iron and Nickel have relatively long range values, indicating that the metal concentration is correlated over a large distance. These trends may suggest that some areas are more prone to heavy metal pollution than others, and that some factors, such as mining activities and mud flow, may influence the spatial distribution of the metals. Therefore, it is important to monitor and manage the heavy metal contamination in rice fields to ensure food safety and environmental health.

Rice grain data interpolation was not necessary, as the data were collected from only two locations, unlike the dust and rice field soil data, which were more spatially dispersed

3.4 PERI Interpretation

The Potential Ecological Risk Index (PERI) values for the three rice field soil samples collected from Santa Cruz, Zambales, reveal significant ecological risks associated with heavy metal contamination. L1 has a PERI of 171,145, L2 has a PERI of 162,430, and L3 has a PERI of 72,280. (See code in Appendix 2). These elevated PERI values indicate a high potential ecological risk, particularly due to the presence of heavy metals like chromium, iron, and nickel. The implication of such high PERI values in an area where mining has been ongoing suggests that mining activities are likely contributing to the increased concentrations of these contaminants in the soil. The ecological risks associated with heavy metal contamination include harm to plant and microbial life, disruption of nutrient cycles, and potential bioaccumulation in the food chain, posing a threat to both ecosystems and human health.



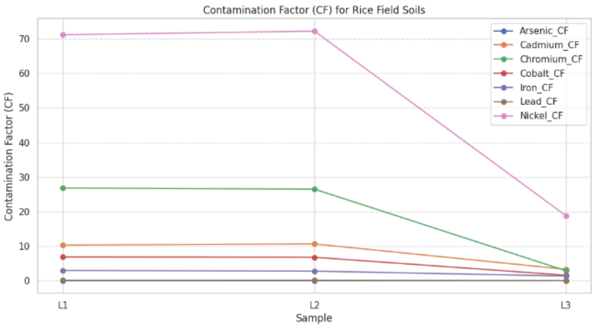


Figure 7a: The Bar plot of the elevated PERI values indicate a high potential ecological risk, particularly due to the presence of heavy metals like chromium, iron, and nickel.

7b: The Line Plot of the Contamination Factor (CF) results for the rice field soils (L1, L2, and L3.)

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3.5 CF Interpretation

The Contamination Factor (CF) results for the rice field soils (L1, L2, and L3.) indicate the degree of contamination for each heavy metal concerning its background concentration. Notably, for Arsenic, all samples show a CF of 0.0, implying that the concentration of Arsenic in the soils is below or equal to its background level, suggesting no significant contamination. Cadmium, Chromium, Cobalt, Iron, and Nickel, on the other hand, exhibit CF values greater than 1, indicating contamination above their respective background levels. Particularly, Nickel shows exceptionally high CF values, reaching 71.18% in L1, 72.21% in L2, and 18.82% in L3, highlighting a substantial contamination of Nickel in these samples. This contamination, especially in the case of Nickel, can pose environmental risks and potential harm to ecosystems.

The presence of these contaminants in the soil poses a significant risk to the ecosystem. Cadmium, Chromium, and Nickel are known to be toxic to plants and can accumulate in the food chain, posing risks to human health through the consumption of contaminated crops. Elevated Iron levels can lead to soil degradation and negatively impact plant growth, affecting agricultural productivity. The implications of high contamination factors include the potential degradation of soil quality, reduced crop yield, and increased health risks for both the environment and humans. The risk is further emphasized by the cumulative effect of multiple contaminants, as reflected in the contamination factor values.

3.5 PLI Interpretation

The Pollution Load Index (PLI) results for the rice field soil samples (L1, L2, and L3 are 16.91, 17.02, and 4.02, respectively); indicating varying degrees of contamination. The elevated PLI values, especially for L2, indicate a substantial level of pollution, potentially posing a high risk to the ecosystem. According to the PLI guideline, values greater than 1 indicate the presence of multiple contaminants and potential pollution. In this context, the elevated PLI values for L1 and

L2 suggest a substantial presence of contaminants in these soil samples, signifying potential pollution. L3, with a comparatively lower PLI, indicates a lower level of pollution but very high as well. The higher PLI values in L1 and L2 may pose ecological risks, especially when the rice fields are exposed to mining waste during flooding. Such contamination can adversely impact the health of the ecosystem, affecting both the soil quality and the crops grown in these fields. The exposure to elevated concentrations of metals like cadmium, chromium, and nickel, as reflected in the PLI values, poses potential risks to both the environment and human health.

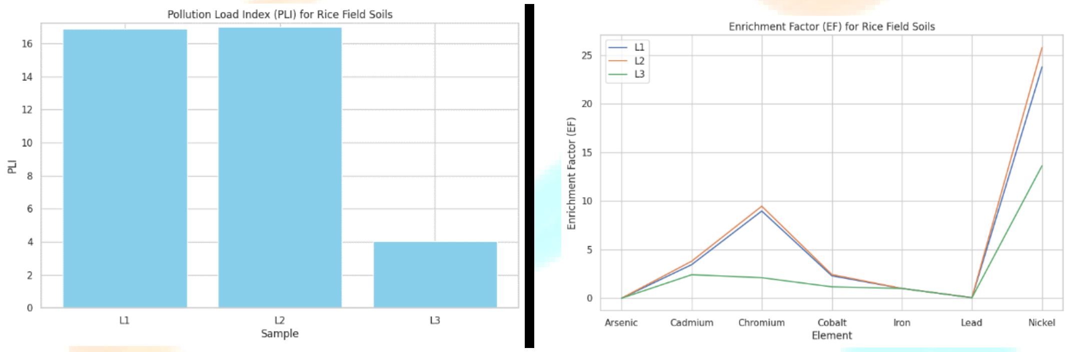

Figure 8a: The Bar Plot of the Pollution Load Index (PLI) results for the rice field soil samples (L1, L2, and L3 are 16.91, 17.02, and 4.02, respectively). 8b: The Line Plot of the Enrichment Factor (EF) results indicate the degree of enrichment of various heavy metals in the three soil samples.

3.6 EF Interpretation

The Enrichment Factor (EF) results indicate the degree of enrichment of various heavy metals in the three soil samples (L1, L2, L3) compared to the background concentrations, with Iron (Fe) serving as the reference element. Here's an interpretation of the results based on the EF interpretation. Arsenic (As): EF values of 0.0 for all samples suggest no enrichment. Arsenic concentrations in the soil samples are equal to or lower than the background levels. This indicates that the levels of arsenic are consistent with natural or background conditions. Cadmium (Cd): The EF values of approximately 3.45, 3.81, and 2.41 for L1, L2, and L3, respectively, indicate medium enrichment as seen in table 1. Cadmium concentrations in the soil samples are moderately higher than the background levels, suggesting a moderate degree of enrichment. This could be attributed to both natural geological processes and human activities. Chromium (Cr): The value of EF are approximately 8.97, 9.46, and 2.11 for L1, L2, and L3, respectively, suggest medium to high enrichment. Chromium concentrations in L1 and L2 are significantly higher than the background levels, indicating potential anthropogenic sources. L3, however, shows lower enrichment, possibly indicating a more natural origin. Cobalt (Co): The EF values of 2.30, 2.43, and 1.17 for L1, L2, and L3, respectively, indicate minimum to low enrichment. Cobalt concentrations in the soil samples are only moderately higher than the background levels, suggesting minimal anthropogenic influence. Moreover, Lead EF values of 0.05, 0.06, and 0.04 for L1, L2, and L3, respectively were obtained, suggesting very low enrichment. Lead concentrations in the soil samples are close to background levels, indicating little influence from anthropogenic sources. Furthermore, the Nickel (Ni) EF values are 23.78, 25.76, and 13.62 for L1, L2, and L3, respectively, indicating very high enrichment. Nickel concentrations in the soil samples are significantly higher than the background levels, suggesting a considerable anthropogenic impact, possibly from the mining of Ni within the locality. These results have implications for the soil ecosystems in the sampled areas. High enrichment of certain metals, especially Nickel, can pose risks to soil health and potentially impact plant and microbial communities. Nickel, in particular, is known for its toxicity to plants and microorganisms. The significant enrichment of Cadmium and Chromium also raises concerns as these metals can have adverse effects on soil quality and pose risks to both terrestrial and aquatic ecosystems.

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Table 1: Enrichment Factor Results

Heavy metals	**L1**	**L2**	**L3**
Arsenic	0	0	0
Cadmium	3.451773	3.806061	2.411674
Chromium	8.965644	9.461088	2.1063
Cobalt	2.301474	2.430297	1.167858
Iron	1	1	1
Lead	0.049596	0.05921	0.044232
Nickel	23.77597	25.764372	13.618867

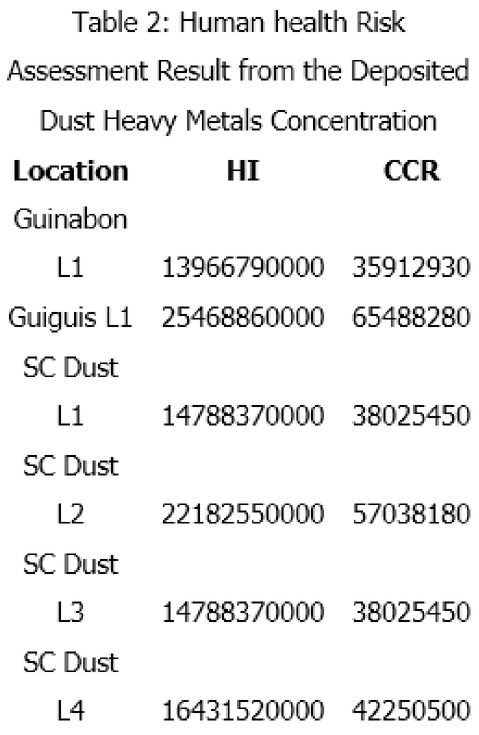


Table 2: Human health Risk Assessment Result from the Deposited Dust Heavy Metals Concentration

Location	**HI**	**CCR**
Guinabon L1	13966790000	35912930
Guiguis L1	25468860000	65488280
SC Dust L1	14788370000	38025450
SC Dust L2	22182550000	57038180
SC Dust L3	14788370000	38025450
SC Dust L4	16431520000	42250500

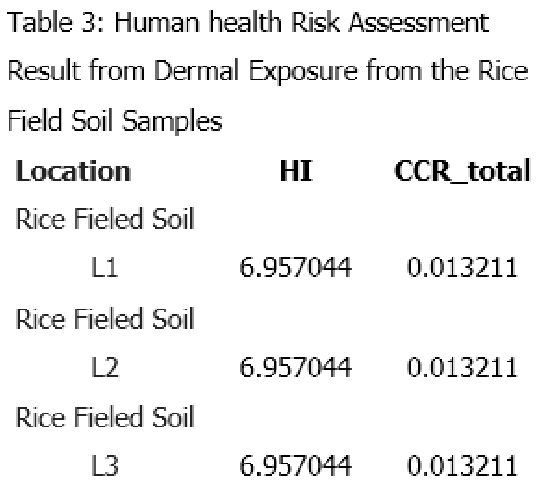


Table 3: Human health Risk Assessment Result from Dermal Exposure from the Rice Field Soil Samples

Location	**HI**	**CCR_total**
Rice Fieled Soil L1	6.957044	0.013211
Rice Fieled Soil L2	6.957044	0.013211
Rice Fieled Soil L3	6.957044	0.013211

3.7 Human Health Risk Assessment from the Deposited Dust Particles

The obtained results indicate significant health risks associated with the sampled and analyzed dust particles from various locations in Santa Cruz, Zambales. The Hazard Index (HI) values, which measure the non-cancer risk, are remarkably high as seen in table 2, ranging from approximately 1.4×10^{10} to 2.5×10^{10} across the different locations. For the Cumulative Cancer Risk (CCR), reflecting the potential cancer risk from exposure to heavy metals, the values range from approximately 3.6×10^{7} to 6.5×10^{7}. These values significantly exceed the generally acceptable range of 10^{-6} to 10^{-4}, indicating a substantial cancer risk for individuals exposed to the sampled dust particles over an extended period. Comparing these results to standard guideline values, the Hazard Index (HI) value should ideally be close to 1 for non-cancer risk, and all the locations exhibit HI values that are astronomically higher. This signifies a severe risk of adverse health effects due to non-cancerous exposure pathways such as inhalation, dermal contact, and oral ingestion.

The Cumulative Cancer Risk (CCR) values, being several orders of magnitude higher than the recommended range, indicate a notable cancer risk associated with exposure to these heavy metals. Such elevated cancer risks are particularly concerning as they suggest a potential for the development of cancer over a lifetime for individuals continuously exposed to the sampled dust particles. The implications of ingesting, inhaling, and exposing oneself to these dust particles, even at a daily intake rate of 1.0 mg per day for an adult Filipino male or female living in those barangays, are alarming. The health risks identified, especially the elevated cancer risks, underscore the urgent need for intervention and remediation measures in these areas. Immediate steps should be taken to minimize exposure pathways and protect the health of the local population, potentially including relocation or thorough cleanup of contaminated areas.

The presence of dust particles containing diverse heavy metals in the streets and roads of Santa Cruz, Zambales, poses an imminent and significant human health risk. This risk is particularly alarming because it indicates a potential failure in the current environmental impact assessment, which seemingly overlooks or underestimates the magnitude of this health hazard. To safeguard the well-being of the local population, there is a compelling argument for policy change and a more comprehensive approach to environmental impact assessments.

Firstly, the current situation signifies a critical oversight in the environmental impact assessment processes, particularly in the context of mining activities in the area. Traditional assessments might focus primarily on direct impacts within mining sites, overlooking the indirect consequences, such as the dispersion of harmful dust particles into surrounding areas. This oversight could be attributed to a narrow scope of assessment that fails to consider the broader implications of mining activities on local communities.

The identified human health risks, as evidenced by the excessively high Hazard Index (HI) and Cumulative Cancer Risk (CCR) values, underscore the urgency for policy change. The current environmental impact assessment practices may not adequately capture the complex dynamics of pollutant dispersion, especially in the form of dust particles, which can travel beyond the immediate vicinity of mining sites. Policy change is needed to enforce a more holistic and proactive approach to environmental impact assessments. This should include a thorough examination of potential pathways for the dispersion of contaminants, such as dust, and the resulting human health risks. Integrating advanced technologies, monitoring systems, and predictive modeling into the assessment process can enhance the accuracy of risk predictions and help identify potential hazards that might have been previously overlooked. Moreover, the argument for policy change should extend to incorporate alternative land use management strategies in the locality. Relying solely on mining without addressing the associated environmental and health risks is unsustainable. There is a need to explore and promote diversified land use practices that can coexist with mining activities without compromising the health and well-being of local communities.

3.8 Human Health Risk Assessment from Dermal Exposure to the Rice Field Soil Samples

The results from the three sampled locations (Rice Field Soil L1, L2, and L3) indicate extremely high Hazard Index (HI) values and Cumulative Cancer Risk (CCR) values as seen in table 3. The HI values for all three locations are 6.957, which is significantly higher than the USEPA guideline value of 1. The HI is an indicator of the potential non-carcinogenic health risk associated with exposure to multiple contaminants. In this case, the HI values suggest a substantial risk to human health due to dermal exposure to the contaminated farm soil.

Similarly, the CCR values for all three locations are 0.0132, exceeding the upper limit of the USEPA guideline range (10^{-4}). The CCR represents the estimated probability of an individual developing cancer over a lifetime as a result of exposure to carcinogenic substances. The elevated CCR values suggest a significant cancer risk associated with dermal exposure to the contaminants in the farm soil.

These extreme values indicate a critical health risk for individuals, particularly rice farmers, who are in direct contact with the contaminated soil. The daily intake rate (IR) via dermal exposure might be underestimated, especially considering that farmers frequently use their hands during planting and are consistently exposed to the soil. This highlights the importance of incorporating realistic exposure scenarios in risk assessments.

The release of mining waste into rice farms poses a serious threat to agricultural activities and, consequently, food safety. If this trend continues, the soil in the rice fields could become too contaminated for planting not only rice but also other crops. This has profound implications for the livelihoods of local farmers and the overall agricultural productivity of the region. These findings underscore the importance of considering not only economic gains from mining activities but also the broader ecological and human health implications. Environmental impact assessments should incorporate comprehensive risk assessments that encompass diverse ecosystem services, including the role of soil in supporting microbial activities and plant growth. Sustainable mitigation strategies is crucial to address the potential long-term consequences of heavy metal contamination in agricultural areas.

The Monte Carlo Simulation results indicate alarming levels of potential health risks associated with exposure to the sampled soil in Santa Cruz, Zambales as seen in table 6. The calculated Hazard Index (HI) values, representing the non-carcinogenic health risks, are significantly elevated, with the 90th percentile exceeding 13.60. This implies a substantial likelihood of adverse health effects, considering that HI values greater than 1 suggest an increased potential for non-cancer-related health issues. The soil in Santa Cruz seems to pose a substantial health risk, particularly in terms of non-carcinogenic effects, based on the conservative estimates provided by the USEPA.

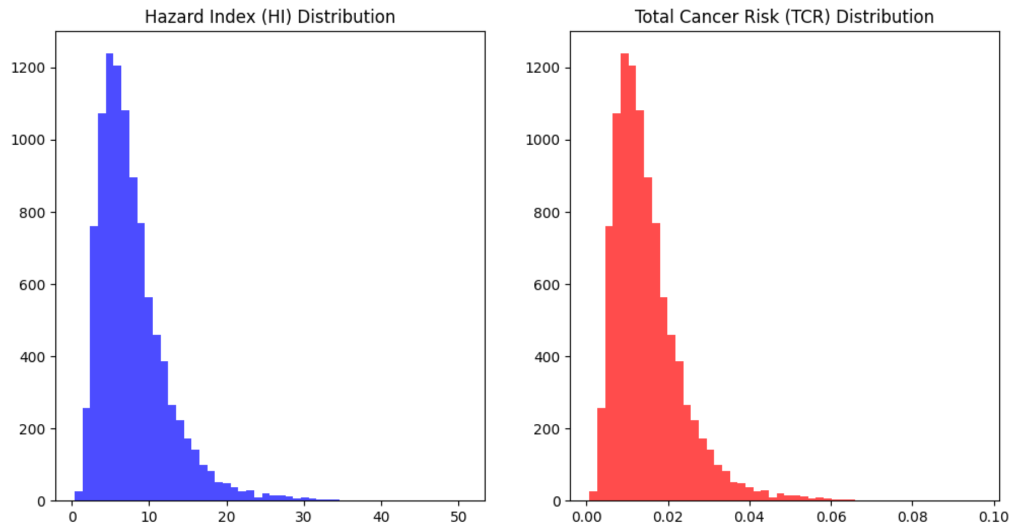


Figure 9: The Monte Carlo Simulation for the rice field soil, considering distributions for exposure parameters and metal concentrations. It then calculates the 25th, 50th, and 90th percentile values for both Hazard Index (HI) and Total Cancer Risk (TCR).

Moreover, the Total Cancer Risk (TCR) values derived from the Monte Carlo Simulation are also remarkably high, especially at the 90th percentile, reaching 0.03. This indicates an elevated probability of cancer-related health risks associated with exposure to the soil. The USEPA typically considers a range between 10^{-6} and 10^{-4} as acceptable for cancer risk; however, the calculated values suggest a heightened risk that is orders of magnitude higher. Such high cancer risk values underscore the urgent need for comprehensive risk management strategies and a reevaluation of current mining practices in the region.

The results underscore the critical importance of adopting a non-deterministic approach in human health risk assessments, as demonstrated by the Monte Carlo Simulation. Traditional deterministic methods may underestimate the true extent of risks associated with environmental exposure, especially in the context of mining activities. The Philippines' mining law, as enforced through the mandated Environmental Impact Assessment (EIA) system, should urgently integrate a more holistic and rational approach to risk assessment. By considering the variability and uncertainties inherent in environmental data, a non-deterministic approach provides a more realistic representation of potential health risks. This approach can better inform regulatory decisions, ensuring the protection of public health and the environment in the face of complex and dynamic mining-related challenges.

Table 4: Human Health Risk Assessment Result for Rice Ingestion

Location	**HI_Total**	**CCR_Total**
Composite Rice Grains L1	4903.896052	3.488617
Composite Rice Grains L2	2967.167485	1.745643

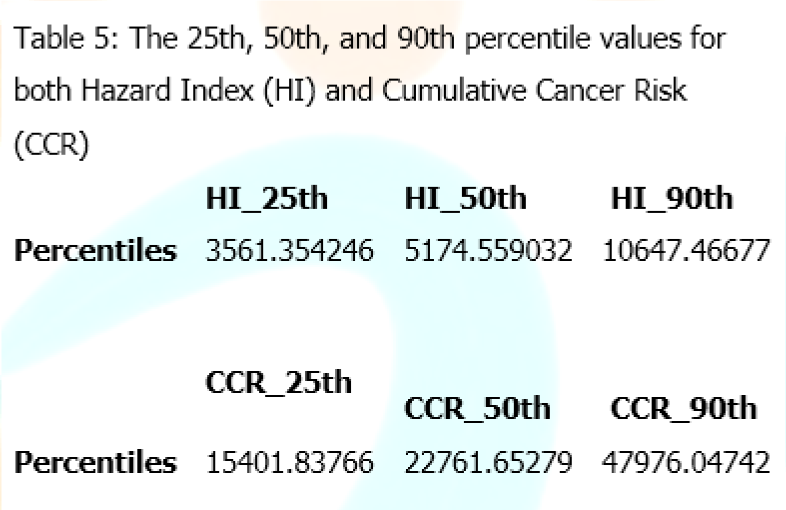


Table 5: The 25th, 50th, and 90th percentile values for both Hazard Index (HI) and Cumulative Cancer Risk (CCR)

	HI_25th	**HI_50th**	**HI_90th**
Percentiles	3561.354246	5174.559032	10647.46677

	CCR_25th	**CCR_50th**	**CCR_90th**
Percentiles	15401.83766	22761.65279	47976.04742

Table 6: The Monte Carlo Simulation for the Rice Field Soil for Both Hazard Index (HI) and Total Cancer Risk (TCR) in Different Percentile Values

HI_25th:	4.75	HI_50th:	6.82	HI_90th:	13.6
TCR_25th:	0.01	TCR_50th:	0.01	TCR_90th:	0.03

3.9 Human Health Risk Assessment Result for Rice Ingestion

The Hazard Index (HI) values for the Composite Rice Grains L1 and L2 locations are alarmingly high, measuring 4903.896 to 2967.1675 respectively with the consumption of 0.5kg (500,000mg) of the rice on the daily basis by the individuals. These values far exceed the USEPA reference range of 1, indicating a substantial non-carcinogenic health risk for individuals consuming rice from these locations as seen in table 4. Specifically, the elevated levels of chromium in the rice pose severe adverse health effects, emphasizing the urgency of addressing contamination issues. On the front of Cumulative Cancer Risk (CCR), the values for Composite Rice Grains L1 (3.5) and L2 (1.7) are considerably higher than the upper limit of the reference range 0.0001 or 10^{-4} established by regulatory standards like USEPA. This signifies an extreme carcinogenic risk for individuals consuming rice from these locations, emphasizing the urgency of addressing contamination issues.

The health implications are profound. Chronic exposure to these contaminants, particularly chromium, can lead to a spectrum of health issues ranging from respiratory problems to organ damage, significantly heightening the risk of cancer for the local population. These findings underscore the inadequacy of current environmental impact assessments (EIAs), which often focus primarily on the economic benefits of mining while neglecting crucial aspects of human health risks.

Incorporating human health risk assessment into future EIAs is imperative for achieving a balanced understanding of the impact of mining activities on local communities. It is crucial to implement immediate measures to reduce heavy metal contamination, particularly in agricultural products such as rice, which forms a significant part of the local diet. Moreover, community awareness initiatives are vital to inform residents about potential health risks and to advocate for sustainable and environmentally friendly mining practices. The extreme values obtained from the risk assessment underscore the urgent need for intervention and regulatory measures to safeguard the health of the local population and ensure the sustainable development activities in the region apart from mining. This comprehensive interpretation emphasizes the gravity of the situation and the critical importance of addressing both non-carcinogenic and carcinogenic risks associated with heavy metal contamination in the studied locations.

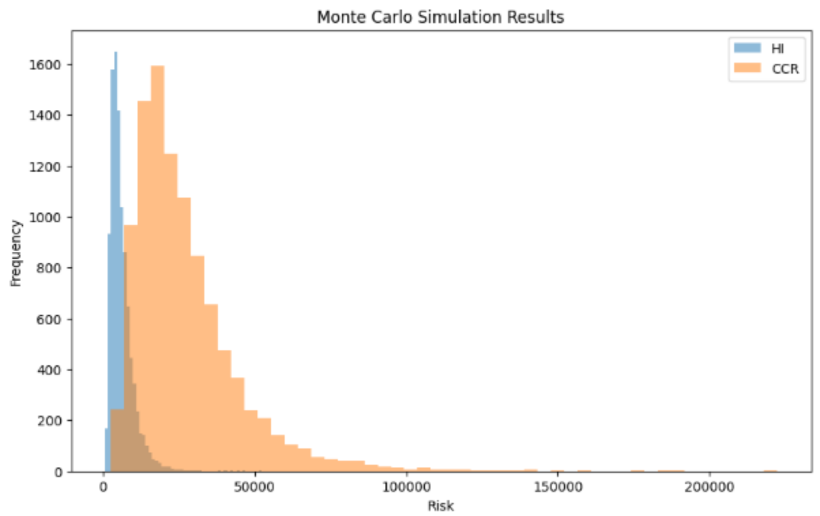


Figure 10: The 25th, 50th, and 90th percentile values for both Hazard Index (HI) and Cumulative Cancer Risk (CCR). Simulation through the Monte Carlo Model.

The results from the Monte Carlo Simulation reveal a spectrum of health risks associated with the ingestion of rice contaminated with heavy metals in Santa Cruz, Zambales seen in table 5. The Hazard Index (HI) at the 25th percentile is 3561.35, indicating a significant probability of non-cancer-related health effects from consuming the contaminated rice. The median HI (5174.56) continues to underscore a substantial health risk, while the 90th percentile HI (10647.47) emphasizes an elevated risk for a significant portion of the population.

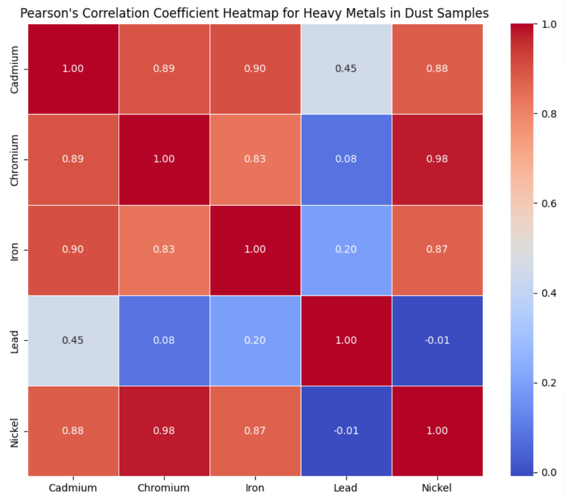
For Cumulative Cancer Risk (CCR), the 25th percentile (15401.84) suggests a notable probability of cancer-related health issues due to long-term exposure to the contaminated rice. The median CCR (22761.65) reinforces the concern, and the 90th percentile CCR (47976.05) highlights a substantial risk of developing cancer over a lifetime. The elevated risks at all percentiles underscore the severity of the health implications for the local population in Santa Cruz. These risks are particularly accentuated due to mining waste contaminating farm soils, impacting the rice cultivation ecosystem. The 25th percentile values indicate a baseline level of risk that is still concerning, and the 90th percentile values highlight an even greater health risk for a significant portion of the population.

The non-deterministic approach employed in the Monte Carlo Simulation is crucial for understanding the inherent variability and uncertainty in environmental risk assessments, especially in the context of mining activities. This approach highlights the need for a more holistic Environmental Impact Assessment (EIA) that incorporates non-deterministic risk assessments. Traditional deterministic approaches, which often rely on fixed or average values, may underestimate the true extent of risks associated with mining waste.

The lack of a holistic EIA that covers non-deterministic risk assessment in Santa Cruz raises serious concerns about the adequacy of existing regulations and guidelines. The mining industry's impact on soil quality and subsequently on rice crops necessitates a comprehensive and adaptable approach to risk assessment. Policies and regulations should be informed by a broader understanding of the variability in exposure parameters and contaminant concentrations to effectively mitigate health risks and protect the well-being of the local population.

3.10 The Statistical Interpretation of the Data

Chromium and Nickel stands out with a correlation coefficient of 0.98, indicating a highly intertwined presence of these metals. This suggests a common source, likely stemming from chromite and nickel mining in Santa Cruz. Chromite ore typically contains nickel as an accessory mineral, explaining their close association in the dust samples. More also, Iron and Chromium with a correlation of 0.90, this further strengthens the link to chromite mining. Iron can also be present in nickel ore deposits as laterites, and mining activities can release dust particles containing both in dry season.



	Cadmium	Chromium	Iron	Lead	Nickel
Cadmium	1.00	0.89	0.90	0.45	0.88
Chromium	0.89	1.00	0.83	0.08	0.98
Iron	0.90	0.83	1.00	0.20	0.87
Lead	0.45	0.08	0.20	1.00	-0.01
Nickel	0.88	0.98	0.87	-0.01	1.00

Figure 11: The Heatmap generated from the Pearson's correlation coefficients, visualization was implemented using seaborn. You can run this code in your Python environment to visualize the correlations between the heavy metals in the dust samples as seen in Appendix of python code.

Cadmium and Lead: While their correlation is slightly lower at 0.62, it still suggests a potential shared source but Cadmium and Nickel are positively correlated 0.88. These metals might be associated with other mining operations. The weak correlation between Chromium and Lead indicate that the source of Chromium must be different from the Lead source which is released in most cases from the vehicles exhaust fumes as the by-products of leaded fuel.

The strong positive correlations point towards mining debris and dust particles released from hauling trucks as potential sources of heavy metal contamination in Santa Cruz. These findings raise concerns about several health and environmental risks. Inhalation of dust containing chromium, nickel, cadmium, and lead can lead to various health problems, including respiratory issues, cancers, and organ damage. Moreover, the dust deposition can pollute soil and water bodies, impacting plant and animal life and these heavy metals can accumulate in the food chain, posing a threat to human health through contaminated food sources.

Furthermore, the Pearson's correlation coefficient heatmap for the heavy metals in the rice farm soil of Santa Cruz reveals interesting insights. Examining the correlation values, it's observed that chromium and nickel exhibit a strong positive correlation with a coefficient of approximately 0.99. This implies that as the concentration of chromium increases in the soil, there is a parallel increase in the concentration of nickel. Such a strong positive correlation might indicate a common source or similar geochemical behavior for these two metals in the soil.

The high positive correlation between chromium and nickel could be attributed to their association with mining activities in Santa Cruz. The waste from nickel and chromite mining, particularly during flash floods, might contribute to the increased levels of both metals in the soil. The erosion of mining waste into the farms could be a significant source of these heavy metals, explaining the strong correlation. Given the potential environmental impact of mining activities, monitoring and controlling the discharge of mining waste is crucial to mitigate soil contamination.

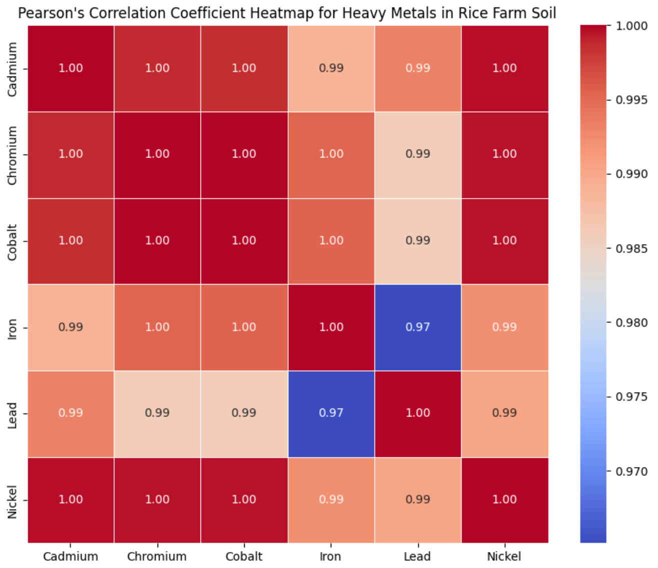


Figure 12: The Heatmap of the Pearson's correlation coefficient measures the linear relationship between pairs of the heavy metals concentration in the soil from the rice fields.

These findings underscore the importance of a comprehensive environmental impact assessment (EIA) in regions like Santa Cruz with active mining. The correlation between chromium and nickel suggests a common origin, likely linked to mining practices. It emphasizes the need for a holistic approach in evaluating the ecological consequences of mining activities, not just for individual metals but also for their potential interactions and collective impact on the environment. This information can guide environmental management strategies and regulatory measures to safeguard agricultural lands and local ecosystems from the adverse effects of heavy metal contamination arising from mining operations.

On implementing similar tool as above on the rice grain obtained from the two composites, Nickel and chromium has a correlation of 1.0, this stands out as the strongest link, suggesting a common source for both metals. This aligns with the presence of chromite and Nickel ore, in this case, the positive correlation coefficient indicates that as the concentration of Chromium increases, there is a tendency for Nickel to also increase. Similarly, nickel and Cobalt and Cobalt with Chromium indicate strong positive correlation at 1.0, further supporting the link to Nickel ore and chromite mining. Cobalt may be present as accessory minerals in Chromite ore, explaining its association with chromium in the rice samples. Interestingly, the strong positive correlations point towards potential contamination of rice fields with heavy metals from mining debris and red-mud released from mine outfalls during flooding. This raises concerns about heavy metal uptake by rice as rice plants can readily absorb heavy metals from soil and water, leading to bioaccumulation in their grains. Hence, consuming contaminated rice poses health risks like gastrointestinal issues, organ damage, and even cancers and with Santa Cruz being a rice-growing and consuming region, contaminated rice poses a significant threat to the health of local communities.

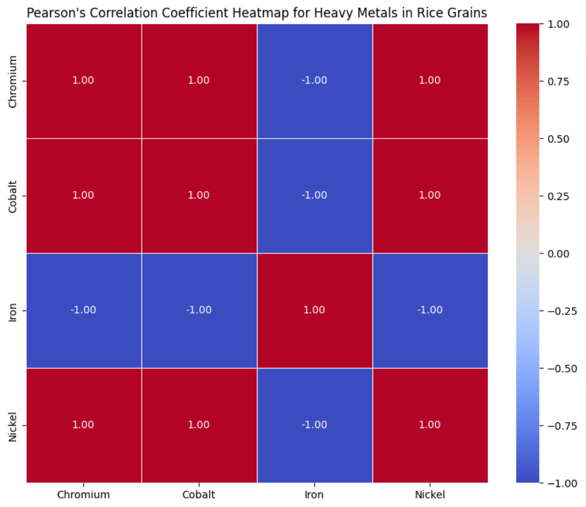


Figure 13: The Heatmap plot of the Pearson's correlation coefficient measures the linear relationship between pairs of the heavy metals concentration in the three composite rice grains samples.

Based on the correlations and the context of Santa Cruz, the likely sources of heavy metals in the rice samples include; Direct deposition of mining debris: During floods, re mud and debris from mine outfalls can directly inundate rice fields, contaminating the soil and subsequently the rice plants. In the same manner, the runoff from contaminated soil from the rainwater can wash away heavy metals from mining-affected areas, transporting them to nearby rice fields through surface runoff.

This is particularly concerning for local residents who consume rice grown in these fields, as they may be exposed to elevated levels of these metals. The significance of these findings underscores the importance of holistic Monitoring Programs and also the need for revision of the current Environmental Impact Assessments (EIAs) that consider only individual metal concentrations. Effort should be made to include also metals interactions and correlations. This systemic approach is essential for comprehensively addressing the health and environmental risks associated with mining activities and their impact on local agriculture.

3.11 The Proposed Rationality-Based Mining Decision Support Model through Cost-Benefit Analysis

Here, we propose the formulation of a comprehensive model integrating health, environmental, and economic data to quantify the costs associated with heavy metals contamination particularly from mining operation as evident from the above ecological and human health risk assessment.

In developing a more effective approach to mining and ecosystem valuation, the proposed model plays a pivotal role by integrating crucial components often overlooked by the Department of Environment and Natural Resources (DENR) and its sister agency Mines and Geoscience Bureau (MGB); whose set of guidelines on mining regulations must be rational.

The proposed framework emphasizes stakeholder engagement and transparency, advocating for a participatory approach in the Environmental Impact Assessment (EIA) process. It highlights the importance of meaningful dialogue among government agencies, mining companies, local communities, and civil society organizations to ensure diverse perspectives are considered and potential impacts are effectively addressed. However, the current regulatory framework, particularly the Environmental Impact Assessment System under RA No. 1586 made provisions for rationality to be applied as an objective clause. Despite the perceived robustness of the policy, it is argued that the lack of adherence to rationality has been evident, particularly in the evaluation of mining permits and the proponents' EIA procurement. To elaborate on this it is necessary to briefly recount a point; being a role of the DENR and as it is identified, as a key player in mining permits procurement and monitoring and permit reapplications; we argue that this agency must transition from its historical lack of adherence to rationality to the application of a holistic assessment before issuing mining permits. The argument is that the current regulatory system ignores rationality in its comprehensive and scientific approach in evaluating submitted Environmental Impact Statements (EIS). This deficiency can be addressed through the proposed rational-based model, which emphasizes robust data collection, computations, and analysis mechanisms. Strengthening institutional capacities for comprehensive assessments is also identified as a crucial step in enhancing the DENR's ability to scrutinize and manage the ecological impacts of mining activities.

In essence, the need for rationality as a defining benchmark in the evaluation of mining permits is underlined. The proposed rational-based model is positioned as a solution to the historical shortcomings, providing a systematic and scientific approach to assess environmental impacts and monitoring and evaluation for permit renewal for mining in the locality comprehensively. By integrating stakeholder perspectives, aligning with existing regulatory frameworks, and emphasizing robust data analysis that captures the interconnected risk as evident in this study, the framework aims to usher in a new era of more informed and responsible decision-making in the mining sector.

Technically, we resolve that by considering the opportunity cost associated with heavy metal contamination remediation, addressing the intricate web of human health risks—both cancer and non-cancer related—linked to heavy metals, and valuing Ecosystem Services, this model offers a more comprehensive and rational framework for evaluating the true costs and benefits of mining activities in Santa Cruz Zambales. The integration of these factors is not just a research exercise; it serves as a pragmatic response to the failure in the implementing the current Philippines mining law which promotes rationality. In doing so, it aligns with the overarching goal of sustainable development, placing emphasis on the multifaceted dimensions of environmental impacts.

Our position is that data sources should be expanded during applications and post EIA monitoring exercises to capture more sampling points and from diverse ecosystem compartments. More also, stakeholder consultations, expert opinions, and public engagement processes must be relied on. With these data interpretation and analysis, it is believed that a more integrative and diverse perspectives could be harness and utilize to support the decision-making techniques to compare and weigh different indicators and criteria, offering a comprehensive assessment of the trade-offs and synergies between mining benefits and ecosystem services. From our research and as documented from literature review, both market-based valuation and multicriteria decision analysis are strategically chosen tools within our Rationality-Based Mining Decision Support Model through Cost-Benefit Analysis, and has emerged as the integral to generating data for the formula: Net Benefit = Mining Proceeds – (Landscape Area Cost + Ecosystem Services Cost + Remediation Cost + Treatment Cancer Cost + Treatment Non-Cancer Cost).

This approach isn't merely about computations and assessments; it is about implementing the very foundation of the Environmental Impact Assessment (EIA) System. By employing rationality into the valuation process which has been stated in the law, our model strives to revitalize various stages of EIA as it should be, from initial monitoring to long-term management strategies. It positions itself as a catalyst for a paradigm shift in implementing the national policies governing mining activities as they are legislated.

The plausible dataset collected, including detailed health, environmental, and economic data, forms the backbone of this ambitious undertaking. These data are not just numbers; they are the building blocks of a transformative decision support model that are very much the definitive frames of rationality in mining context. As Santa Cruz navigates the complexities of its mining sector, this model aims to guide it towards a future where informed decision-making is at the core of sustainable development, fostering resilience against the environmental and health challenges posed by mining operations.

On this note, we remained firm that creating a comprehensive cost-benefit model involves integrating multiple factors, each contributing to the overall economic evaluation and below is a simplified mathematical model followed by the python code snippet that outlines the basic structure of a cost-benefit model, considering health costs, environmental remediation costs, and ecosystem valuation.

3.12 Rationality-Based Mining Decision Support Model through Cost-Benefit Analysis: With an illustrative computation for easy adoption

$$\begin{aligned} Net\ Benefit = {} & Mining\ Proceeds \\ & - (Landscape\ Area\ Cost + Ecosystem\ Services\ Cost + Remediation\ Cost \\ & + Treatment\ Cancer\ Cost + Treatment\ Non - Cancer\ Cost) \end{aligned}$$

$$NB = MP - (LAC + ESC + RC + TCC + TCNC)$$

Where:

NB is the Net Benefit,

MP is the Mining Proceeds,

LAC is the Landscape Area Cost,

ESC is the Ecosystem Services Cost,

RC is the Remediation Cost,

TCC is the Treatment Cancer Cost,

TCNC is the Treatment Non-Cancer Cost.

The decision rule should typically be expressed as a condition:

$$Decision = \{"Mine" if\ > 0\ "Do\ Not\ Mine"\ otherwise$$

Python Code Illustration

```
# Define the input variables (all in pesos)
landscape_area_cost = 1000000  # Cost over the landscape area
ecosystem_services_cost = 500000  # Potential ecosystem services cost
remediation_cost = 2000000  # Remediation cost over the affected area at risk
treatment_cancer_cost = 1500000  # Cost of treatment of cancer over the populations at risk
treatment_non_cancer_cost = 800000  # Cost of treatment of non-cancer diseases over the populations at risk
mining_proceeds = 5000000  # Capital (monetary benefits) generated from mining proceeds
```

```
# Model formula: Net Benefit = Mining Proceeds - Total Costs
net_benefit = mining_proceeds - (landscape_area_cost + ecosystem_services_cost +
                                remediation_cost + treatment_cancer_cost +
treatment_non_cancer_cost)

# Decision rule
if net_benefit > 0:
    decision = "Mine"
else:
    decision = "Do Not Mine"

# Display results
print(f"Net Benefit: {net_benefit} pesos")
print(f"Decision: {decision}")
```

Net Benefit could be calculated as the difference between the mining proceeds and the total costs (landscape area (current real estate value/cost), ecosystem services, remediation, and treatment costs). The decision rule is to mine if the net benefit is positive; otherwise, the decision is not to mine.

3.13 CONCLUSIONS

The province of Zambales, particularly in Santa Cruz as a case study is renowned for its abundant mineral resources, has witnessed a surge in mining activities, particularly in nickel, chromite, and copper. However, this expansion has raised concerns regarding its ecological and socio-economic repercussions. Studies have highlighted significant damages caused by mining operations, impacting forests, rivers, agricultural lands, and the health of local communities. The urgent need for assessing ecosystem services, ecosystem risk and human health risk in areas susceptible to mining, like Santa Cruz Zambales, has been underscored by emphasizing the necessity for a methodological consensus and policy-oriented frameworks for holistic assessments of mining impacts.

The current threats to the ecosystem services, ecological structures and functions coupled with human health risk need to be evaluated and we propose that such is required by the law as it outlines that mining operations should be rational, hence, it is essential that with this approach, mining projects design could be enhanced, management be sustainable- garnering stakeholder support, contributing to increased project success and the well-being of both humans and nature in the context of mining. On this note, we argue that the existing process of permitting, monitoring and post EIA programs in the Philippines fail to comprehensively address these challenges by not implementing rational mining scheme. A rethinking by the DENR is imperative for three primary reasons. First, the current implementation approach inadequately considers ecosystem and human health risk assessment and valuation using deterministic and non-deterministic risk assessment factors and the multiple risks associated with mining activities, hindering a holistic understanding of the potential impacts and hence, could be considered not rational. Second, the absence of ecological risk assessment, landscape valuation, human health risk assessment, remediation cost, and ecosystem valuation in the evaluation process overlooks the economic contributions of ecosystem services, limiting the assessment to direct monetary gains from mining alone hence, not rational. Lastly, the lack of a rational-based model for cost-benefit analysis neglects a systematic evaluation of the trade-offs between mining benefits and ecological health, leading to suboptimal decision-making.

The following key elements have been identified and executed in this research;

1) Severe heavy metal contamination: The analysis of heavy metal contamination in Santa Cruz, Zambales, reveals alarming levels of metals like Nickel, cadmium, chromium in various environmental matrices, including dust, soil, and rice grains. These findings indicate a significant health risk for the local population due to chronic exposure through multiple pathways.

2) Interconnected risks: The correlation analysis highlights the interconnectedness of heavy metal concentrations in different environmental samples. Particularly, nickel and chromium mining activities show strong positive correlations, suggesting a common source or similar transport mechanisms. This interconnectedness exacerbates the overall health risk, making a comprehensive risk assessment imperative.

3) Cost-Benefit Analysis for mining decision support: The proposed Cost-Benefit Analysis (CBA) model offers a rational and comprehensive approach to mining decision-making. By integrating factors such as remediation costs, health treatment costs, and ecosystem services valuation, the model provides a holistic perspective. The extremely high health risks and costs associated with heavy metal contamination, as revealed in the analysis, argue for a careful reconsideration of mining activities in Santa Cruz.

4) Importance of both deterministic and non-deterministic risk assessment: The use of Monte Carlo Simulation in the risk assessment process emphasizes the significance of non-deterministic approaches. The probabilistic outcomes, especially in cancer risk assessment, highlight the uncertainties and variability associated with the exposure parameters. This approach underscores

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the need for a more nuanced and adaptable risk assessment strategy, considering the dynamic nature of environmental conditions.

From the above analysis and synthesis, it is hereby recommended that;

1. Immediate remediation and health intervention be implemented in Santa Cruz Zambales. Given the severity of heavy metal contamination and the associated health risks, urgent remediation efforts and health interventions are crucial. Immediate steps should be taken to reduce exposure pathways, conduct health screenings for the local population, and implement remediation measures in highly contaminated areas.
2. Enhanced Environmental Monitoring: Strengthening the implementation of the environmental monitoring programs is essential for tracking contamination levels over time. Regular sampling and analysis of air, soil, water, and food sources should be conducted to provide real-time data for risk assessments and early intervention.
3. Holistic Environmental Impact Assessment (EIA): The current EIA system should be fully implemented to incorporate a more holistic approach, considering non-deterministic risk assessments on ecosystems and human health concerns. This involves accounting for uncertainties in exposure parameters, using probabilistic models, and emphasizing the interconnectedness of different environmental factors.
4. Community Engagement and Policy Advocacy: Engaging local communities in decision-making processes and advocating for policy changes at the national level are critical. Community members should be informed about the risks associated with mining activities, and their input should be considered in policy decisions. Advocacy for stricter regulations and enforcement can contribute to sustainable and responsible mining practices.
5. Implement an Adaptive Management Framework within the Proposed Cost-Benefit Analysis (CBA) Model. This involves continuous refinement of the model based on ongoing data collection, technological advancements, and evolving scientific insights. An adaptive

approach acknowledges the dynamic nature of environmental systems and allows for real-time adjustments to risk assessments, remediation strategies, and valuation metrics. Regular updates to the CBA model ensure that it remains a robust and responsive tool for decision-makers, enabling timely interventions and a more accurate representation of the complex interactions between mining activities, environmental health, and economic considerations.

These findings underscore the urgency of addressing heavy metal contamination in Santa Cruz, Zambales, and the broader implications for mining practices in the Philippines. The proposed Cost-Benefit Analysis model, coupled with enhanced risk assessment strategies, can guide more informed and responsible decision-making towards the full implementation of rationality in mining projects, prioritizing both environmental sustainability and public health. By adopting these measures, the monitoring and post EIA processes can better capture the intricate dynamics between mining activities, ecosystem services, and human well-being, fostering more informed and responsible decision-making in land use management.

Statement of conflict of interest

The authors declare no conflict of interest regarding the sampling, analysis, writing and publication of this research. The study was conducted with impartiality and adherence to scientific rigor, independent of any financial or personal affiliations that could potentially bias the findings or conclusions presented herein.

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APPENDIX A

DUST SAMPLE (50-70µm ONLY)	ARSENIC (mg/kg)	CADMIUM (mg/kg)	CHROMIUM (mg/kg)	COBALT (mg/kg)	IRON (mg/kg)	LEAD (mg/kg)	NICKEL (mg/kg)	N	E	ELEVATION (m)
Guinabon L1		1.7	1,370		68,100	3.2	3,240	15° 47'42.25	119° 59'30.52	
Guiguis L1		3.1	3,040		184,000	4	7,230	15° 47'59.50	119° 58'47.13	
SC Dust L1		1.8	456		56,500	4.7	1,750	15° 46'04.20	119° 54'28.62	
SC Dust L2		2.7	2,590		95,600	4.8	5,420	15° 44'43.67	119° 54'32.21	
SC Dust L3		1.8	1,580		70,000	3.1	4,180	15° 44'34.04	119° 53'41.99	
SC Dust L4		2	1,710		69,400	3	4,550	15° 41'45.62	119° 56'05.81	
RICE GRAIN (POWDERED >10µ)								N	E	
Composite Rice Grains L1	ND	ND	4	1	380	ND	13	15°47'13.52	119°57'47.00	
Composite Rice Grains L2	ND	ND	2	0.5	390	ND	7	15°43'02.81	119°57'41.19	
RICE FARM SOIL (Sediment)	ARSENIC (mg/kg)	CADMIUM (mg/kg)	CHROMIUM (mg/kg)	COBALT (mg/kg)	IRON (mg/kg)	LEAD (mg/kg)	NICKEL (mg/kg)	N	E	
Rice Fieled Soil L1	ND	3.1	2,480	175	141,000	3.4	4,840	15° 47'12.66	119° 57'42.97	
Rice Fieled Soil L2	ND	3.2	2,450	173	132,000	3.8	4,910	15° 47'15.15	119° 58'23.79	
Rice Fieled Soil L3	ND	1	269	41	65,100	1.4	1,280	15° 43'02.81	119° 57'41.19	
SURFACE WATER	ARSENIC (mg/L)	CADMIUM (mg/L)	CHROMIUM (mg/L)	COBALT (mg/L)	IRON (mg/L)	LEAD (mg/L)	NICKEL (mg/L)	N	E	
Kabaluan River	>0.005		0		5		0	15°46'18.27	120° 03'28.09	
Estuarine S.Water	>0.005		1		27		1	15° 44'50.83	119° 53'23.39	
Bayto Dam	>0.005		0		12		1	15° 43'00.55	119° 58'00.44	
Freshwater Well (Source)	>0.005		>0.005		0		>0.006	15° 46'48.79	119° 57'31.87	
Sta. Cruz Bridge	>0.005		0		6		0	15° 45'35.89	119° 54'46.28	
Bayto River	>0.005		1		66		3	15° 43'12.69	119° 54'37.05	
DENR Water Qlty Guidelines (mg/L)										
AA	0.01		0.01		1		0.02			
A	0.01		0.01		1		0.02			
B	0.01		0.01		1		0.04			
C	0.02		0.01		1.5		0.2			
D	0.04		0.02		7.5		1			
SA	0.01		0.05		1.5		0.02			
SB	0.01		0.05		1.5		0.04			
SC	0.02		0.05		1.5		0.06			
SD	0.04		0.1		7.5		0.3			

Appendix B

All codes for the computations are on the principal author's github public repository:

https://github.com/GeoPrince

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