IJGGSD
ISSN: 3155-7716
International Journal of Global Goals and Sustainable Development
RESEARCH | INNOVATION | INCLUSION | SUSTAINABLE FUTURES
DOI: https://doi.org/10.65339/ijggsd.V1.I1.93

Spatial Distribution and Phytoaccumulation of Lead in Soils and Plants Adjacent to Mining Areas in Surigao Del Norte

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ABSTRACT

This study assessed the spatial distribution of lead (Pb) in soils and its accumulation in *Saccharum spontaneum* adjacent to a mining-affected area in Mainit, Surigao del Norte, Philippines. Using a quantitative field approach, soil and plant samples were purposively collected at 0, 50, and 200 m; Pb in soil extracts and roots, stems, and leaves was quantified using atomic absorption spectrophotometry. Mean concentrations, standard deviations, one-way analysis of variance, and plant-to-soil bioaccumulation factors (BAFs) were determined. Mean soil Pb declined numerically from 5.314 ± 1.365 mg/kg at 0 m to 3.376 ± 0.281 mg/kg at 200 m, but differences were not statistically significant ($p = 0.0576$). Pb occurred in all examined plant parts; the highest mean concentration was observed in roots at 50 m (6.451 ± 2.539 mg/kg), with no significant distance-related differences for roots, stems, or leaves. BAFs were below 1 at 0 m and above 1 at 50 and 200 m. Thus, Pb occurrence and tissue-specific accumulation were documented without establishing a significant distance effect or phytoremediation suitability. Periodic monitoring and expanded sampling, including soil characterization and validated total-Pb measurement, are recommended. The restricted study area, single species, limited sampling, and acid-extraction method constrain wider inference and direct screening-level comparisons. The findings provide local baseline evidence to inform site-specific environmental assessment and potential land rehabilitation, supporting SDG 15 (Life on Land) and SDG 3 (Good Health and Well-Being), with indirect relevance to SDG 6 (Clean Water and Sanitation).

Keywords: *Bioaccumulation Factor, Lead Contamination, Mining Areas, Phytoaccumulation, Saccharum Spontaneum, Spatial Distribution, Surigao Del Norte*

1. INTRODUCTION

Lead (Pb) contamination remains a significant environmental concern because of its persistence, toxicity, and potential accumulation in soils and living organisms. Mining activities contribute to the release and redistribution of Pb through mineral extraction, waste disposal, and the movement of contaminated materials. These processes may affect surrounding vegetation and create potential pathways for ecological and human exposure (Darma et al., 2022; Mathee et al., 2022). The extent of contamination varies according to proximity to pollution sources, environmental conditions, and the capacity of plants to absorb and accumulate metals (Collin et al., 2022; Rahman et al., 2024). Recent investigations have demonstrated the importance of assessing heavy metal contamination in Philippine mining environments. Sabijon et al. (2024) examined heavy metals in agricultural soils affected by mining activities in Samar, while Mainit et al. (2025) investigated metal contamination and rhizosphere bacterial communities associated with *Saccharum spontaneum* in rehabilitated nickel-laterite mining areas in the Philippines. These studies emphasize the importance of site-specific environmental assessments, particularly in areas where mining activities may affect soil quality and vegetation. The present study investigated the spatial distribution and phytoaccumulation of Pb in soils and *Saccharum spontaneum* adjacent to mining areas in Surigao del Norte. It examined soil and plant tissue concentrations at different sampling distances to provide baseline evidence for environmental monitoring, contamination assessment, and potential land rehabilitation initiatives.

Research Problem

The persistence and movement of Pb in mining-affected environments present challenges to environmental protection and sustainable land management. Pb may accumulate in soils and become available for plant uptake, although its mobility and absorption depend on soil characteristics, plant species, and environmental conditions (Xu et al., 2022; Rahman et al., 2024). Consequently, soil contamination does not necessarily produce uniform Pb concentrations in different plant tissues. Spatial investigations have demonstrated that contamination may vary with distance from mining operations. Mathee et al. (2022) reported decreasing soil Pb concentrations with increasing distance from a mine tailings facility in South Africa. Similarly, Akbar et al. (2024) investigated heavy metal concentrations in soils and plants at sampling distances of 50, 100, and 200 meters from coal mining areas, demonstrating the relevance of distance-based sampling for environmental contamination assessment. However, distance alone does not fully explain Pb distribution and accumulation. Soil properties, environmental transport processes, and plant physiological characteristics may modify contamination patterns (Xu et al., 2022; Rahman et al., 2024). Furthermore, the accumulation of Pb differs among plant species and tissues, highlighting the need to evaluate roots, stems, and leaves separately (Collin et al., 2022). Although recent Philippine research has examined mining-related heavy metals and the potential role of native vegetation in land rehabilitation (Sabijon et al., 2024; Mainit et al., 2025), site-specific information on the distribution of Pb in soils and its accumulation in different tissues of *Saccharum spontaneum* at defined distances from mining areas in Surigao del Norte remains necessary. Accordingly, this study addressed the need to determine the concentrations of Pb in soils and plant tissues at 0, 50, and 200 meters from the selected mining area, assess differences across sampling distances, calculate bioaccumulation factors, and evaluate measured concentrations against appropriate environmental reference values. The findings are intended to strengthen local environmental monitoring and provide evidence relevant to contamination assessment and future rehabilitation planning.

Assumptions of the Study

The study was guided by the assumption that the distribution of Pb in soils and plants may vary according to sampling distance, environmental conditions, and plant tissue characteristics. Existing research indicates that proximity to mining activities can be associated with differences in soil metal concentrations, although the magnitude and direction of these differences depend on local environmental conditions (Mathee et al., 2022; Akbar et al., 2024). It was further assumed that Pb concentrations measured in the roots, stems, and leaves of *Saccharum spontaneum* could provide information about its accumulation and internal distribution. Plant uptake and movement of Pb are affected by soil chemistry, physiological barriers, and tissue-specific accumulation mechanisms (Collin et al., 2022; Rahman et al., 2024). For the interpretation of the data, the study also adopted the operational assumption that properly collected and analyzed soil and plant samples could provide comparable measurements across the selected sampling locations. Nevertheless, differences in Pb concentrations would be interpreted as observed spatial patterns rather than definitive evidence that sampling distance alone caused the variations.

Objectives of the Study

The primary objective of this study was to assess the spatial distribution and phytoaccumulation of Pb in soils and *Saccharum spontaneum* adjacent to mining areas in Surigao del Norte. Specifically, it aimed to determine Pb concentrations in soils collected at 0, 50, and 200 meters from the mining area; measure Pb concentrations in the roots, stems, and leaves of *Saccharum spontaneum* at the selected distances; determine whether significant differences existed in soil Pb concentrations across sampling distances; establish whether Pb concentrations in individual plant parts differed significantly across distances; calculate the bioaccumulation factors of Pb in the roots, stems, and leaves; and compare measured Pb concentrations with applicable environmental screening levels or scientifically appropriate reference values. These objectives support the assessment of contamination patterns and soil–plant metal accumulation, consistent with recent investigations of heavy metal distribution and plant uptake in mining-affected environments (Darma et al., 2022; Akbar et al., 2024).

Theoretical or Conceptual Basis

This study was grounded in the contemporary scientific concepts of soil–plant metal transfer, bioaccumulation, and spatial contamination distribution. Bioaccumulation describes the uptake and accumulation of substances within living organisms, while plant metal translocation concerns the internal movement of accumulated elements between different tissues. These processes are influenced by soil metal availability, plant physiology, and environmental conditions (Collin et al., 2022; Rahman et al., 2024). The conceptual framework considered sampling distance from mining areas (0, 50, and 200 meters) and plant tissue type (roots, stems, and leaves) as the principal grouping variables. The measured variables were Pb concentrations in soils and the corresponding plant tissues. Bioaccumulation factors and comparisons with appropriate reference values served as additional indicators for interpreting the distribution and accumulation of Pb. The bioaccumulation factor was calculated as the ratio of Pb concentration in a specific plant tissue to the corresponding soil Pb concentration, using comparable concentration units. This approach provides a quantitative indication of the relative accumulation of Pb in plant tissues. However, bioaccumulation factors alone cannot establish whether a plant is an effective hyperaccumulator or whether it possesses demonstrated phytoremediation capacity (Darma et al., 2022; Collin et al., 2022). The framework therefore recognizes that spatial proximity, soil characteristics, and plant physiological mechanisms may collectively explain variations in Pb concentration. Recent research involving *Saccharum*

spontaneum in Philippine rehabilitated mining soils further supports its relevance as a species for investigating vegetation responses in mine-affected environments (Mainit et al., 2025).

The study is primarily aligned with SDG 3 – Good Health and Well-Being and SDG 15 – Life on Land, with an indirect contribution to SDG 6 – Clean Water and Sanitation. Its alignment with SDG 3, particularly Target 3.9, concerns the prevention and reduction of health risks associated with hazardous chemicals and environmental contamination. By identifying Pb concentrations in soils and vegetation, the study contributes environmental information that may support exposure prevention and public health monitoring. This relevance is supported by evidence that lead exposure can affect neurological, cardiovascular, and renal health (Surenbaatar et al., 2023; World Health Organization, 2025). The study also supports SDG 15, particularly Target 15.3, which emphasizes the restoration of degraded land and soil. Determining the distribution and accumulation of Pb in mining-affected environments can provide baseline information for environmental assessment and the development of soil rehabilitation initiatives. Research on heavy metal bioremediation in the Philippines demonstrates the potential importance of vegetation and plant-associated biological processes in restoring contaminated soils (Trocio & Paguntalan, 2023; Mainit et al., 2025). Additionally, the study has indirect relevance to SDG 6, particularly Target 6.3, through its potential contribution to the prevention and management of contamination that may migrate from mining-affected soils into surrounding water systems. However, because water quality was not directly examined, this contribution is limited to providing supporting information for environmental pollution prevention rather than evidence of improved water quality. Overall, the study contributes to environmental, ecological, public health, and community sustainability by providing locally relevant evidence on Pb distribution and plant accumulation. Its findings may inform environmental monitoring, future risk assessments, and evidence-based land management practices in mining-affected communities.

2. METHODOLOGY

Research Design

The study employed a quantitative descriptive-experimental research design to assess variations in Pb concentrations in soils and plant tissues at different distances from mining areas. Quantitative research involves systematically collecting and analyzing numerical data to identify patterns, relationships, and differences among variables (Riazi, 2016). Descriptive research examines observable conditions without manipulating variables (Omair, 2015), whereas experimental research investigates relationships between independent and dependent variables under controlled conditions (Creswell, 2014). Sampling distance served as the independent variable, with measurements obtained at 0, 50, and 200 meters from the mining-affected area. The 0-meter sampling location was designated as the point of origin and served as the reference or control point, while the 50-meter and 200-meter locations served as comparison points for assessing the spatial variation of Pb concentrations in soil and plant parts. The dependent variables were Pb concentrations in soils and the roots, stems, and leaves of *Saccharum spontaneum*. These distances provided a basis for comparing spatial variations in Pb concentrations and evaluating accumulation among plant parts.

Research Locale or Study Setting

The study was conducted in a selected barangay in Mainit, Surigao del Norte, Philippines, near a gold mining area and an affected tailings storage facility. The municipality had a reported population of 29,205 based on the 2024 census information, an elevation of approximately 261.92 meters above sea level, and a tropical rainforest climate classified as Af. The research site was selected because of its proximity to mining operations and a tailings storage facility that

could contribute to the redistribution of Pb in surrounding soils and vegetation. Sampling locations were established at 0, 50, and 200 meters from the affected area to assess spatial differences in Pb contamination and plant accumulation.

Participants or Data Sources

The study utilized soil and plant samples collected through non-probability purposive sampling, which involves selecting sampling units based on their relevance to the research objectives (Ayhan, 2011). Samples were collected at three predetermined distances from the affected tailings area: 0, 50, and 200 meters. Three independent soil samples were collected at each sampling distance. *Saccharum spontaneum* was the only plant species examined to maintain consistency in assessing Pb accumulation across locations. Approximately 500 grams of whole plant material, comprising roots, stems, and leaves, were collected at each sampling site using grab sampling. The plant specimens were authenticated by a forestry and dendrology expert from the College of Forestry and Environmental Studies, Mindanao State University–Zamboanga Sibugay, and a certificate of identification was obtained. Species authentication was necessary because heavy metal accumulation may vary among plant species (Orellana et al., 2019).

Research Instruments or Materials

Pb concentrations in soil and plant parts were determined at Davao Analytical Laboratories, Inc., located at McArthur Highway, corner Union Avenue, Matina, Davao City, using a Shimadzu AA-7800 Atomic Absorption Spectrophotometer manufactured in 2025. The soil extraction procedure was adapted from Section 5.4, "Standard Operating Procedure for Measurement of Extractable Metals in Soils" (pp. 150–152), of the *Quality Assurance Methods Manual for Laboratory Analytical Techniques* by Robarge and Fernandez (1986), while plant tissue analysis followed the *Standard Methods of Analysis for Soil, Plant Tissue, Water and Fertilizer* of the Philippine Council for Agriculture, Aquatic and Natural Resources Research and Development (PCAARRD, 1991, pp. 88-98). The materials included a flat-tip shovel, clean polyethylene sampling bags, drying trays, an oven, an electric chopper, laboratory sieves, a muffle furnace, porcelain crucibles, volumetric flasks, hydrochloric acid solutions, and Whatman No. 42 filter paper. A GAIA GPS Version 2026.7 mobile application was used to record sampling locations. Analytical calibration employed certified Pb standard solutions from CPAchem Ltd., with a certified concentration of 99.97 ± 0.29 mg/L and metrological traceability to NIST SRM 3126a (Lot 140812). Pb concentrations were reported in parts per million (ppm) on a dry-weight basis.

Data Gathering Procedure

Soil and plant samples were collected at 0, 50, and 200 meters from the mining-affected area. At each sampling distance, three independent soil samples were obtained from a 4 m^2 sampling area (Ding et al., 2017). Surface debris was removed before approximately 500 grams of soil were collected to a depth of 20 cm using a flat-tip shovel. Samples were placed in clean, labeled polyethylene bags and tightly sealed to minimize contamination during handling and transportation (Orellana et al., 2019). Approximately 500 grams of *Saccharum spontaneum* were collected at each sampling location, with roots, stems, and leaves separated for analysis. Foreign materials and deteriorated plant tissues were removed, while adhering soil and water-soluble contaminants were gently brushed or washed away using clean, cold distilled water (Du et al., 2018). The plant tissues were dried at 70°C for 48 hours (Nawab et al., 2015), ground into fine powder using an electric chopper, and passed through a 2 mm sieve. Processing equipment was cleaned before and after use to prevent cross-contamination (Orellana et al., 2019). Soil samples were air-dried at room temperature under dust-free conditions. Stones, roots, and other

foreign materials were removed before the samples were pulverized and passed through a 125 µm sieve to obtain homogeneous material. Prepared samples were placed in clean, labeled containers and stored under dry conditions before laboratory analysis (Surenbaatar et al., 2023). For soil extraction, approximately 5.0 grams of prepared soil were placed in a 250 mL Erlenmeyer flask containing 100 mL of 0.1 N hydrochloric acid. The mixture was shaken for one hour, allowed to settle for 30 minutes, and filtered through Whatman No. 42 filter paper. The filtrate was transferred into an acid-washed polyethylene container, diluted as required, and analyzed for Pb using AAS. For plant tissue preparation, approximately 1.0 gram of dried sample was placed in a porcelain crucible and ashed in a muffle furnace at 550°C for five hours. After cooling, the ash was dissolved in 2 N hydrochloric acid, allowed to stand for 15–20 minutes, and transferred into a 50 mL volumetric flask using hot distilled water. The mixture was allowed to settle for approximately 30 minutes and filtered when necessary, before AAS analysis. Pb concentrations were determined using the calibration curve, appropriate volume and dilution factors, and the dry weight of the samples. Instrument calibration and analytical quality control were performed using certified reference materials, reagent blanks, duplicate analyses, and three aspirations per sample. The method's detection limits were 0.05 ppm for soil and 0.02 ppm for plant tissues. Certified reference material recovery was evaluated using an acceptance range of 90–110%, while reagent blanks were required to produce results below the method detection limit.

Data Analysis

Data were analyzed using descriptive statistics and one-way ANOVA through Statistical Package for the Social Sciences (SPSS) software. Mean values were calculated to determine the average Pb concentrations in soils and individual plant tissues at each sampling distance. Standard deviations were used to assess variability, with concentrations reported as mean ± SD. Relative standard deviation (RSD) was employed to evaluate the precision and consistency of repeated AAS measurements. Separate one-way ANOVA tests were used to determine whether Pb concentrations in soils, roots, stems, and leaves differed significantly across the three sampling distances of 0, 50, and 200 meters. Bioaccumulation factors were calculated by dividing Pb concentrations in individual plant tissues by the corresponding soil Pb concentrations (BAF = Cplant/Csoil). Values greater than 1 indicated that the measured tissue concentration exceeded the corresponding soil concentration, whereas values below 1 indicated lower tissue concentrations relative to soil (Roque-Álvarez et al., 2018). These calculations were used to characterize Pb accumulation patterns across plant tissues and sampling distances. Measured Pb concentrations were also compared with the environmental and regulatory reference values identified in the study to assess their relative levels.

Ethical Consideration

The study was conducted in accordance with established principles of research integrity, transparency, accountability, and environmental responsibility. Field sampling, sample preparation, laboratory analysis, and data processing were documented to support the reliability and reproducibility of the findings. The researcher coordinated with the academic adviser, research panel, and laboratory personnel to ensure the proper implementation of the research procedures. Laboratory analyses were conducted in an ISO/IEC 17025:2017-accredited testing laboratory. The researcher, a Registered Chemist, observed laboratory safety procedures during sample preparation, chemical handling, and instrumental analysis. Appropriate personal protective equipment was used, and procedures involving acids and volatile chemicals were performed in a fume hood. Laboratory equipment was maintained regularly, and work areas were kept clean and adequately ventilated to minimize chemical exposure, environmental hazards, and sample contamination.

3. RESULTS AND DISCUSSION

3.1 Spatial Distribution of Pb in Soils and Plant Tissues

3.1.1 Pb Concentrations in Soils at Varying Distances

Pb was detected in soil samples collected at all three distances from the mining area. The highest mean Pb concentration was recorded at 0 meters (5.314 ± 1.365 ppm), followed by 50 meters (3.804 ± 0.120 ppm), while the lowest concentration was observed at 200 meters (3.376 ± 0.281 ppm). These results demonstrated a numerical decrease in soil Pb concentrations with increasing distance from the mining area. The observed distribution is consistent with studies reporting spatial variations in Pb concentrations around mining-affected environments. Mathee et al. (2022) documented higher soil Pb concentrations with increasing proximity to mine tailings, while Akbar et al. (2024) identified distance-related differences in heavy metal concentrations in soils near coal mining areas. Similarly, Sabijon et al. (2024) reported spatial variations in heavy metals in Philippine agricultural soils affected by mining activities. However, contamination patterns may also reflect soil characteristics and environmental transport processes. The present findings therefore indicate a decreasing numerical trend without establishing mining activities as the sole source of Pb.

3.1.2 Pb Concentrations in Roots, Stems, and Leaves

Pb was detected in the roots, stems, and leaves of *Saccharum spontaneum* at all sampling distances. At 0 meters, the highest mean concentration was recorded in leaves (4.836 ± 0.186 ppm), followed by roots (4.475 ± 0.669 ppm) and stems (3.715 ± 0.709 ppm). At 50 meters, roots exhibited the highest concentration (6.451 ± 2.539 ppm), followed by stems (5.210 ± 1.137 ppm) and leaves (4.832 ± 1.476 ppm). At 200 meters, stems showed the highest concentration (4.476 ± 1.415 ppm), followed by leaves (3.978 ± 1.105 ppm) and roots (3.848 ± 0.500 ppm). The highest overall mean Pb concentration occurred in roots at 50 meters, demonstrating that plant tissue concentrations did not follow a uniform decreasing pattern with distance. Variations in tissue concentrations are consistent with the complex mechanisms governing Pb uptake, accumulation, and translocation in plants. Rahman et al. (2024) explained that Pb distribution depends on soil properties, metal availability, and plant physiological characteristics. Lazo et al. (2024) similarly demonstrated differences in Pb accumulation between roots and aerial tissues of plants grown in mine tailings. Furthermore, Nunn et al. (2025) established that surface deposition of Pb-contaminated dust can contribute to measured concentrations in vegetation. These findings suggest that the distribution observed in *Saccharum spontaneum* may reflect several interacting environmental and physiological processes rather than sampling distance alone.

3.2 Statistical Differences in Pb Concentrations Across Sampling Distances

3.2.1 Differences in Soil Pb Concentrations

One-way analysis of variance revealed no statistically significant difference in soil Pb concentrations among the three sampling distances ($F = 4.767$, $p = 0.0576$) at the 0.05 significance level. Although mean concentrations decreased from 5.314 ± 1.365 ppm at 0 meters to 3.376 ± 0.281 ppm at 200 meters, the observed differences were not statistically significant. Consequently, the null hypothesis was not rejected. This finding differs from the significant distance-related variations reported by Akbar et al. (2024) in soils surrounding coal mining areas. Differences among investigations may be associated with site-specific environmental conditions, soil properties, and sampling characteristics. Salazar et al. (2024) emphasized that

the bioavailability of potentially toxic elements in mine tailings depends on physicochemical conditions and may differ from total metal concentrations. Similarly, Sabijon et al. (2024) demonstrated the importance of local soil characteristics when assessing heavy metals in Philippine mining-affected landscapes. The limited number of soil samples in the present study may also have reduced statistical power to detect differences across sampling distances.

3.2.2 Differences in Plant Tissue Pb Concentrations

The one-way ANOVA results indicated no statistically significant differences in Pb concentrations across sampling distances for roots ($F = 2.325$, $p = 0.1788$), stems ($F = 1.324$, $p = 0.3340$), or leaves ($F = 0.640$, $p = 0.5598$). Although roots and stems exhibited their highest mean Pb concentrations at 50 meters, while leaves showed their highest mean at 0 meters, none of these variations reached statistical significance at the 0.05 level. Therefore, the null hypothesis was not rejected for any of the three plant tissues. These findings suggest that sampling distance was not associated with statistically detectable differences in Pb concentrations within individual plant tissues under the conditions examined. Rahman et al. (2024) identified soil chemistry, metal availability, and plant physiological mechanisms as important factors influencing Pb uptake and translocation. Sarathchandra et al. (2024) also demonstrated that soil amendments and physicochemical conditions can affect metal accumulation in plants grown in mine tailings. In the Philippine context, Mainit et al. (2025) examined heavy metal contamination in rehabilitated mining soils associated with *Saccharum spontaneum*, emphasizing the importance of site conditions in evaluating mining-affected vegetation. These findings support the need to consider environmental factors beyond distance when interpreting plant Pb concentrations.

3.3 Bioaccumulation Factors of Pb in Plant Tissues

3.3.1 Bioaccumulation Patterns Across Sampling Distances

The calculated BAF values varied among plant tissues and sampling distances. At 0 meters, all values were below 1, with 0.842 for roots, 0.699 for stems, and 0.910 for leaves. At 50 meters, BAF values exceeded 1 in all tissues, reaching 1.696 in roots, 1.370 in stems, and 1.270 in leaves. At 200 meters, the corresponding values were 1.140, 1.326, and 1.178. The highest BAF was recorded in roots at 50 meters, whereas stems exhibited the highest BAF at 200 meters. These values indicate that the calculated plant-to-soil concentration ratios differed across sampling distances and tissues. The differences in BAF values are consistent with research demonstrating species-specific and tissue-dependent metal accumulation. Darma et al. (2022) reported variations in the transfer of Pb from mining-affected agricultural soils to cultivated plants, while Lazo et al. (2024) demonstrated that the accumulation and translocation of Pb differed between plant species and tissues. Nevertheless, BAF values alone are insufficient to establish phytoremediation capacity. Nunn et al. (2025) highlighted that externally deposited Pb-containing particles may contribute to measured plant concentrations independently of biological uptake. Moreover, because the present study used hydrochloric acid extraction for soil samples and ashing-based preparation for plant tissues, differences in the measured Pb fractions must be considered when interpreting the calculated ratios. Additional investigation of Pb bioavailability, plant biomass, metal tolerance, and translocation is necessary before establishing the phytoremediation potential of *Saccharum spontaneum*.

3.4 Comparison of Pb Concentrations with Environmental Reference Values

3.4.1 Soil Pb Concentrations and Environmental Screening Levels

The mean soil Pb concentrations at all sampling distances were numerically below the United States Environmental Protection Agency (2025) residential soil lead screening level of 200 mg/kg. The recorded concentrations were 5.314 ± 1.365 mg/kg at 0 meters, 3.804 ± 0.120 mg/kg at 50 meters, and 3.376 ± 0.281 mg/kg at 200 meters. Although Pb was detected in every sampling area, none of the reported mean concentrations exceeded the selected numerical benchmark.
The United States Environmental Protection Agency (2025) established the 200 mg/kg residential soil screening level for evaluating potential lead exposure concerns at designated contaminated sites. However, this value is intended for residential soil assessment and is not a universal regulatory threshold for Philippine mining environments. Furthermore, the present study measured Pb using an acid-extraction procedure rather than an explicitly documented total-soil digestion method. Consequently, numerical comparisons with the screening level cannot independently establish regulatory compliance or environmental safety. Nolos et al. (2025) demonstrated the importance of site-specific soil contamination and exposure assessments in Philippine communities with histories of mining-related environmental disturbances. Salazar et al. (2024) likewise emphasized the distinction between bioavailable and pseudo-total metal concentrations when evaluating environmental risk. These findings support cautious interpretation of the present soil Pb measurements.

3.4.2 Pb Concentrations in Plant Tissues and Reference Values

Pb concentrations were detected in all examined plant tissues at the three sampling distances. The mean concentrations ranged from 3.848 ± 0.500 to 6.451 ± 2.539 mg/kg in roots, 3.715 ± 0.709 to 5.210 ± 1.137 mg/kg in stems, and 3.978 ± 1.105 to 4.836 ± 0.186 mg/kg in leaves. All reported mean concentrations were numerically higher than the 2.00 mg/kg contextual comparison value used in the original manuscript. The highest mean concentration occurred in roots at 50 meters, while measurable Pb was present in all examined tissues at 200 meters. These findings demonstrate the presence of Pb in both belowground and aboveground tissues of *Saccharum spontaneum*. However, the 2.00 mg/kg contextual comparison value cannot be treated as an established regulatory limit specifically applicable to this wild grass without verification of its original scope and intended use. Rahman et al. (2024) explained that the accumulation and internal distribution of Pb depend on plant physiological characteristics and environmental conditions. Nunn et al. (2025) further demonstrated that measured Pb in vegetation may include contributions from surface contamination. The presence of Pb in all examined plant parts therefore provides evidence of plant-associated contamination but does not, by itself, establish toxicity, dietary exposure, or phytoremediation effectiveness. The findings underscore the importance of further environmental monitoring and detailed assessment of soil–plant interactions in mining-affected areas.

4. CONCLUSIONS AND RECOMMENDATIONS

This study established that lead (Pb) was detected in all soil and *Saccharum spontaneum* samples collected at 0, 50, and 200 meters from a mining-affected area in Mainit, Surigao del Norte. Mean soil Pb concentrations decreased numerically with increasing distance, although the differences were not statistically significant. Pb was also detected in roots, stems, and leaves, with the highest concentrations occurring at different sampling distances rather than consistently nearest the mining area. No statistically significant differences were established for individual plant tissues across distances. Calculated bioaccumulation factors were below 1 at 0

meters and above 1 at 50 and 200 meters, indicating variations in plant-to-soil Pb concentration ratios. Although measured soil concentrations were numerically below the selected residential screening level, this comparison does not establish environmental safety. Overall, the findings provide site-specific evidence of Pb occurrence and plant-associated accumulation without confirming a significant distance effect or the phytoremediation suitability of *Saccharum spontaneum*.

Environmental authorities and mining-site stakeholders should strengthen periodic monitoring of Pb concentrations in soils and surrounding vegetation to support contamination assessment and environmental management. Additional sampling locations, greater numbers of independent replicates, and repeated sampling periods are recommended to determine whether the observed spatial patterns remain consistent. Future investigations should evaluate soil pH, organic matter, texture, and other relevant environmental characteristics to better understand variations in Pb distribution and availability. Laboratories should employ validated total or near-total digestion methods when determining total soil Pb concentrations and clearly distinguish these measurements from acid-extractable Pb. Further assessment of *Saccharum spontaneum* should include plant biomass, Pb tolerance, root-to-shoot translocation, and metal removal capacity before establishing its potential for phytoremediation. Comparisons with environmental or regulatory reference values should use standards appropriate to the analytical method, plant species, and exposure context. These measures may improve environmental monitoring and support evidence-based rehabilitation planning in mining-affected communities.

The study was limited to one mining-affected locality in Mainit, Surigao del Norte, three sampling distances, and a single plant species, restricting the generalizability of its findings. The relatively small number of independent soil samples may have reduced statistical power to detect differences across distances. Soil characteristics and environmental factors potentially affecting Pb distribution were not directly examined, while sampling did not establish temporal variations. Additionally, soil Pb was determined using acid extraction rather than total digestion, limiting direct comparisons with total-soil screening values. Future studies may address these limitations through expanded sampling, repeated measurements, and additional soil and plant analyses.

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