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# Analysis of soil physicochemical characteristics and heavy metal concentrations in Lourdes, Alubijid, Misamis Oriental

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## ABSTRACT

Soil quality assessment is essential for understanding the ecological health of freshwater-influenced environments and in determining potential risks posed by heavy metal contamination. In areas where communities depend on soil and water resources, establishing baseline information on physicochemical characteristics and heavy metal concentrations provides crucial support for environmental management and protection initiatives. This study assessed the physicochemical characteristics and the levels of selected heavy metals (cadmium, copper, chromium, cobalt, lead, manganese, and nickel) in soil samples collected from Lourdes, Alubijid, Misamis Oriental, and compared these values with established soil quality standards. Samples were obtained from purposively selected sampling locations near a river, a waterfall and a creek that represent different freshwater-influenced environments. Results showed no significant differences across soils sampled among stations in terms of pH, conductivity, salinity, total dissolved solids, temperature, and moisture content. Only organic matter was observed to vary significantly across sites reflecting localized environmental conditions and potential anthropogenic influences. Metal concentrations were highest in soil sampled near the river, followed by the waterfall, and the creek. Chromium exceeded the permissible limits at all stations indicating serious contamination concern. Nickel, and cobalt also showed elevated levels in both stations (near the creek and the river) suggesting site-specific contamination patterns, whereas copper, lead, and cadmium remained within safe thresholds. These findings highlight the need for targeted source tracing, continuous monitoring, including standards-based risk assessment to better understand contamination dynamics, especially for metals that exceeded guideline values, to guide appropriate mitigation or remediation strategies in the area.

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## INTRODUCTION

Altered physicochemical properties and rising heavy metal concentration in soil are a growing global concern. Heavy metals' persistence and bioaccumulative properties threaten soil health, hinder plant growth, affect water quality, and increase health risks in humans (Ali and Khan, 2019; Edo *et al.*, 2024; Vasilachi and Gavrilescu, 2023; Rashid *et al.*, 2023), undermining the attainment of the 2030 agenda on land, water, and sanitation. Moreover, the health and sustainability of soil are pivotal to the well-being of ecosystems and communities (Stronge *et al.*, 2020). This calls for the urgency of assessing the physicochemical characteristics and the heavy metal concentrations in water-influenced soils, to understand their impact and take informed, decisive actions for environmental stewardship.

Heavy metals in soil originate from both natural and anthropogenic sources, although the latter exert the most significant impact on soil quality (Li *et al.*, 2019; Kumar and Gandhi, 2022; Kumar *et al.*, 2022). Natural inputs include parent material composition, volcanic activity, and the redistribution of soil particles through wind and water processes. In water-influenced environments such as Alubijid, heavy metals can be transported and deposited in soil through surface runoff, sedimentation, and flooding events (Jayakumar *et al.*, 2021). However, anthropogenic activities including mining and smelting operations, industrial discharge, agricultural runoff, irrigation, and the application of fertilizers and pesticides are also the dominant contributors to heavy-metal accumulation in soils (Zhang and Wang, 2020). Urbanization and industrial development have intensified soil contamination worldwide (Durdu *et al.*, 2023; Swain, 2024), thus putting riverine systems at risk (Cunha *et al.*, 2021).

The Alubijid River system and soil resources play a significant role in maintaining the environmental quality of the region. Alubijid River is one of the twelve river systems in Northern Mindanao and is recognized as an important potential source of both surface and groundwater (Puno and Barro, 2016; Walag *et al.*, 2018) that influences soil physicochemical properties and heavy metal dynamics (Ma *et al.*, 2025). Currently, there is no available empirical evidence on the levels of heavy metals in soils and physicochemical characteristics in the said locality. This lack of localized baseline data of heavy metal concentration, such as cadmium (Cd), copper (Cu), chromium (Cr), cobalt (Co), lead (Pb), manganese (Mn), and nickel (Ni), as well as the physicochemical characteristics, hinders efforts to assess environmental and public health risks accurately.

## MATERIALS AND METHODS

### Study location and description

Alubijid is a municipality in Region X (Northern Mindanao), Philippines, and forms part of the Metro Cagayan de Oro Center, the country's fourth metropolitan center (NEDA, 2023). This Municipality contributes to agricultural production, coastal and freshwater resources, and ecological services. It is also known for its traditional salt-making industry, tourist destinations, religious and historical sites, and rapidly growing community. Lourdes, one of the most populous among the municipality's sixteen barangays of Alubijid, is situated at approximately 8°31' North, 124°26' East, away from the coastline, with an estimated elevation of 36.4 meters (119.4ft) above mean sea level and is bordered by Benigwayan, Tugasnon, Sampatulog, Lapad, and Gregorio Pelaez (Lagutay) of Gitagum, Misamis Oriental (Lourdes, Alubijid, Misamis Oriental Profile – PhilAtlas, 1990). The study focused on the three strategic locations in Barangay Lourdes, particularly in areas near a river, a waterfall, and a creek. These were carefully selected based on proximity to water sources, including vegetation, as these are known to influence soils' physicochemical properties and heavy metal accumulation, which can help provide a relevant basis for interpretation of results.

### Sampling procedure

The study used the non-composite grab soil sampling technique, where sample soils were collected from three (3) identified areas with three substations each, with sample soils extracted from 20-cm deep dig from the surface. These soil samples were obtained from sites 0-100 m near a creek, a waterfall, and a river to represent different freshwater-influenced environments in the area. Following the standard protocol, soil samples were collected and placed in sealed plastic bags and transported to the laboratory for processing. Collected soils were prepared by manually removing coarse materials such as pebbles, roots, and other foreign debris. These soils are then dried, powdered, pulverized, disaggregated, homogenized, and sieved to extract fine soil samples prior to physicochemical characterization and heavy metal determination.

### Physicochemical analysis

The physicochemical parameters of soil samples were determined through in situ and laboratory analyses. All instruments used were calibrated based on the manufacturer's specifications before field measurements. Soil electrical conductivity, salinity, and pH were determined using a portable soil conductivity and pH meter, while total dissolved solids (TDS) were determined using a calibrated portable TDS meter. Turbidity measurements were obtained using a portable turbidimeter. Instrument readings were recorded only after stabilization, ensuring accuracy. Soil moisture content and temperature were also assessed in situ using a portable XLUX Soil Moisture meter. These measurements were taken directly to capture the prevailing conditions at the time of the sample collection. On the other hand, soil organic matter content was determined in the laboratory using the UV-VIS Spectrophotometric method, following established analytical procedures.

### Heavy metal analysis

The soil samples collected were prepared by manually removing coarse materials like pebbles, roots, and other foreign debris. The soils were air-dried for several days, then pulverized, disaggregated, homogenized, and sieved to extract fine soil samples using a 75 µm mesh. These homogenized samples were then weighed to 0.5000 g and poured into a 250 mL beaker and transferred to a microwave digestion vessel. Digestion was carried out by adding 15 ml of aqua regia (3:1 concentrated HCl: $HNO_3$). Microwave-assisted digestion was performed for 30 minutes in a controlled condition. After digestion, the vessels were allowed to cool to approximately 500 °C. The beaker and its walls were rinsed with distilled water, and the digested solution was quantitatively transferred through filter paper into a 100 mL volumetric flask. The solution was diluted to volume with distilled water, stoppered, and mixed thoroughly, ready for Atomic Absorption Spectrophotometric (AAS) reading (Apat, 2023).

## RESULTS AND DISCUSSION

Presented in Table 1 are the mean values and standard deviations of soil physicochemical characteristics of samples measured across the three sampling stations. Overall, the results indicate no significant variation in soil properties in terms of pH, conductivity, salinity, total dissolved solids (TDS), temperature, and moisture content (all $p>0.05$). In contrast, organic matter differed significantly among stations (F (2,6) = 12.91, $p$ = 0.007). Indicating a site-specific variation likely linked to localized environmental conditions, including potential anthropogenic influences.

### Soil pH

As shown, soil pH did not vary significantly across the three stations, F (2,6) = 0.58, $p$ =0.59. The pH values ranging from 7.45 to 7.78 indicate slight soil alkalinity, which may favor alkaline adaptive plants. Station 3 exhibited the highest mean pH (7.78), followed by Station 1 (7.60) and Station 2 (7.45). The standard deviations are relatively small and show stable pH conditions within each station. As known, alkaline soils can influence nutrient availability, as pH is a very important indicator of soil quality (Hermiyanto *et al.*, 2025), affecting the mobility of heavy metals, often reducing their solubility (Soltan and Ismail, 2019).

### Conductivity

As observed, the soil conductivity showed no significant variations among stations, F (2,6) = 1.37, $p$ = 0.32. Station 2 recorded a relatively higher mean conductivity (234.93 µS/cm) compared to Station 3 (102.07 µS/cm) and Station 1 (14.53 µS/cm). The large variability in Station 2 indicates notable differences within the area, possibly due to localized inputs of dissolved ions from runoff, agricultural activities, or soil disturbance. These recorded values indicate less than the desired range for many plants to thrive. Typically, the optimal electrical conductivity (EC) range for plant growth is 800 - 1800 µS/cm, with an upper tolerance limit of approximately 2500 µS/cm (Ahmad *et al.*, 2025).

### Salinity

The recorded salinity values were generally low across all stations and showed no significant variation, F (2,6) =1.03, $p = 0.41$, with Station 1 showing the highest mean (2.27 ppt) when compared. However, the large standard deviation suggests uneven salt distribution within this station. Stations 2 and 3 exhibited very low salinity levels, which might indicate little to no salt influence, implying that soil salinization is not a major concern in these sampled areas. Overall, the low salinity levels observed among all stations are generally favorable for soil quality and plant growth, as elevated salinity is known to adversely affect soil structure, nutrient availability, and soil productivity (Hailu and Mehari, 2021; Maurya *et al.*, 2020; Muhammad *et al.*, 2024).

### Total dissolved solids (TDS)

The total dissolved solids did not vary significantly in all three stations, F (2,6) = 1.67, $p = 0.26$, and exhibited a pattern like that of electrical conductivity. Station 2 had the highest mean TDS (125.97 mg/L), followed by Station 3 (23.24 mg/L) and Station 1 (8.23 mg/L). The relatively elevated TDS values in Station 2 indicate higher dissolved minerals when compared to other stations, although levels across all stations remain relatively low when compared to 560-3500 ppm for maximum plant growth (Raj *et al.*, 2023; Prabu *et al.*, 2023). This further supports the presence of lower dissolved mineral content, which may affect soil structure and plant nutrient uptake. Together, TDS and electrical conductivity are commonly used as indicators of soil salinity for soil quality assessments (Corwin and Yemoto, 2020).

### Soil temperature

Among the three stations, soil temperature also did not vary significantly, F (2,6) = 4.07, $p = 0.08$. A gradual decreasing trend in temperature is observed from Station 1 to Station 3. Station 1 recorded the highest mean temperature (30.53 °C), while Station 3 had the lowest (28.13 °C). This low variability suggests consistent microclimatic conditions within each station, which may possibly be related to the area's vegetation cover, soil moisture, or shading.

### Moisture content

Moisture content did not vary significantly across the 3 stations, F (2,6) =0.19, $p = 0.83$. The soil moisture ranged from 23.87% to 28.13%, with Station 2 exhibiting the highest mean moisture content (28.13 %), while Station 3 showed greater variability (SD = 10.87), indicating uneven water retention capacity, which may be influenced by soil texture and organic matter content. Soil moisture plays a critical role in regulating soil organic carbon dynamics (Kerr and Ochsner, 2020), thus affecting soil quality.

### Organic matter content

As shown, there is significant variation in organic matter values across the three stations, F (2,6) =12.91, $p$ =0.007. Tukey's HSD ($\alpha = 0.05$) indicated that Station 1 vs Station 2 was not significant, whereas Station 1 vs Station 3 and Station 2 vs Station 3 were significantly different, confirming a decrease from Station 1 to Station 3. Station 1 had the highest mean organic matter (16.05 %), followed by Station 2 (13.67 %) and Station 3 (9.18 %). Higher organic matter levels enhance soil fertility and may reduce heavy metal bioavailability through adsorption and complexation processes.

Overall, most measured parameters in Table 1 did not differ significantly among stations, except that organic matter showed a significant site-specific variation, with higher values at Station 1 and lower values at Station 3, as confirmed by Tukey's HSD test. Station 2 was characterized by relatively higher conductivity and TDS, suggesting greater dissolved mineral content, while Station 1 exhibited higher organic matter content and greater within-site variability in salinity. These soil properties are very relevant indicators of heavy metal mobility and plant uptake which provide essential information in interpreting the geographical distribution of heavy metals in soils and vegetation across the study area.

**Table 1.** Physicochemical characteristics of soil across the three sampling stations

| Physicochemical characteristics values | Station 1 Near the river Mean ± SD | Station 2 Near the waterfalls Mean ± SD | Station 3 Near the creek Mean ± SD |
|---|---|---|---|
| pH | 7.6 ± 0.56 | 7.45 ± 0.25 | 7.78 ± 0.199 |
| Conductivity (µS/cm) | 14.53 ± 5.12 | 234.93 ± 273.76 | 102.07 ± 78.30 |
| Salinity (ppt) | 2.27 ± 3.75 | 0.1 ± 0.17 | 0.03 ± 0.06 |
| TDS (mg/L) | 8.23 ± 3.04 | 125.97 ± 148.14 | 23.24 ± 11.58 |
| Temperature (°C) | 30.53 ± 1.10 | 29.73 ± 1.43 | 28.13 ± 0.21 |
| Moisture (%) | 26.27 ± 9.6 | 28.13 ± 3.27 | 23.87 ± 10.87 |
| Organic Matter (%) | 16.05 ± 2.17 | 13.67 ± 1.72 | 9.18 ± 0.96 |

**Table 2.** Analysis of variance (ANOVA) of heavy metal concentrations across sampling stations

| Metal | Station 1 Near the river Mean ± SD | Station 2 Near the waterfalls Mean ± SD | Station 3 Near the creek Mean ± SD | F-value | *p*-value |
|---|---|---|---|---|---|
| Copper | 56.66 ± 9.37 | 60.6 ± 4.77 | 101.33 ± 7.36 | 100.38 | 0.001 |
| Chromium | 3966.78 ± 44.97 | 2994.22 ± 456.27 | 1584.56 ± 231.49 | 146.84 | 0.0001 |
| Lead | 15.74 ± 7.87 | 10.82 ± 5.79 | 7.29 ± 10.94 | 2.26 | 0.126 |
| Cobalt | 192.46 ± 45.40 | 130.44 ± 10.66 | 35.02 ± 9.25 | 75.13 | 0.001 |
| Manganese | 1535 ± 372.70 | 1139.11± 116.84 | 999.14 ± 91.70 | 12.96 | 0.0001 |
| Nickel | 2130.56 ±75.76 | 1789.89 ± 74.0 | 383.01± 145.77 | 714.97 | 0.0001 |
| Cadmium | nd* | nd* | 9.4 ± 0.46 | 52.99 | 0.0001 |

*nd= not detected

Table 2 provides the one-way ANOVA outputs, highlighting which heavy metals show statistically significant differences across the sampling stations. These results are essential for validating observed trends and determining which contaminants require focused monitoring or further investigation. As presented, copper concentrations in soil varied significantly among the three stations, F (2,24)= 100.38, *p*= .001. Station 3 exhibited higher copper levels than Stations 1 and 2, while no significant difference was observed between the latter two. The relatively elevated copper at Station 3 suggests localized enrichment, likely influenced by anthropogenic activities such as urban runoff, in addition to possible natural contributions from mineral-rich sediments (Li *et al.*, 2020).

Chromium concentrations in soil differed significantly among the three stations, F (2, 24) = 146.84, *p* < .001. Station 1 had the highest mean concentration, followed by Station 2 and Station 3 showing a clear decreasing trend among the sampled areas. These pronounced differences are likely influenced by both localized anthropogenic sources as well as geogenic contributions. The increasing pattern from Station 3 to Station 1 suggests the accumulation of metal-bearing sediments in the low-lying Alubijid River reach, where downstream transport favors deposition. Contamination of the environment by Chromium may arise from anthropogenic but it can also originate from naturally enriched geological formations such as ultramafic rocks and their derived soils (Jeřábková *et al.*, 2018). Lead concentration did not differ significantly among sampling stations, F (2, 24) = 2.26, *p* = .126. Mean concentrations were highest at Station 1, followed by Station 2 and Station 3. The overlapping confidence intervals indicate that observed differences likely reflect natural variability rather than localized contamination. While Station 1 showed the highest means, substantial within-site variability suggests that further sampling and analysis are needed to accurately assess potential ecological or human health risks.

Cobalt differed significantly among sampling stations, F (2, 24) = 75.13, *p* = .001, with Station 1 showing the highest mean concentration, followed by Station 2, and the lowest at Station 3. The large differences between stations suggest that the high cobalt levels at Stations 1 and 2 are likely to be due to human activities or urban runoff. Station 3's lower levels likely reflect natural background concentrations. Cobalt, together with Chromium, emerges as a key contaminant of concern, warranting site-specific source tracking and monitoring at identified hotspots.

**Table 3.** Mean heavy metal levels in soil relative to permissible standards

| Metals | Permissible limit in ppm** | Stations | | |
|---|---|---|---|---|
| | | 1 | 2 | 3 |
| Copper | 3100 | 56.66 | 60.6 | 101.33 |
| Chromium | 380 | 3966.78 | 2994.22 | 1584.56 |
| Lead | 400 | 15.74 | 10.82 | 7.29 |
| Cobalt | 50 | 192.46 | 130.44 | 35.02 |
| Manganese | 2000 | 1535 | 1139.11 | 999.14 |
| Nickel | 1000 | 2130.56 | 1789.89 | 383.01 |
| Cadmium | 17 | nd* | nd* | 9.4 |

*Station 1 near the river, Station 2 near the waterfalls, and Station 3 near the creek

*nd = not detected, **Source: Apat (2023)

Manganese concentrations in soil differed significantly among sampling stations, F (2, 24)= 12.96, $p$ < .001. Station 1 exhibited the highest means, followed by Station 2 and Station 3. The non-overlapping confidence intervals indicate a clear spatial gradient, with elevated manganese levels at Station 1 likely influenced by localized anthropogenic inputs, or urban runoff, whereas lower levels at Station 3 may reflect natural geogenic background concentrations.

Nickel concentrations in soil differed greatly across sampling stations, F (2, 24) = 714.97, $p$ < .001 decreasing from S1 > S2 > S3. Tukey's HSD (α = 0.05) confirmed that all stations differed significantly from one another. Elevated concentrations at Stations 1 and 2 may result from localized anthropogenic activities and urban runoff, while the lower levels at Station 3 likely reflect natural background levels. These results identify nickel as a priority contaminant for site-specific monitoring and risk assessment.

Cadmium was not detected in soils from Stations 1 and 2, whereas Station 3 exhibited a low mean concentration (M = 1.04 ppm, 95% CI [0.71, 1.38]). A one-way ANOVA indicated a statistically significant difference among stations, F (2, 24)= 52.99, $p$ < .001; however, the absence of detectable levels at Stations 1 and 2 suggests that cadmium contamination is largely localized. The measurable presence of cadmium at Station 3 may reflect site-specific anthropogenic inputs, while the undetectable concentrations at the other stations likely correspond to natural background levels. These findings highlight that cadmium contamination in the area is minimal and confined to specific locations, emphasizing the importance of targeted monitoring and assessment.

Table 3 presents a comparison of the mean concentrations of heavy metals across the three sampling stations relative to established permissible limits. Shown in the table, is the concerning concentration of chromium in all three monitoring stations. The mean values of chromium exceeded substantially when compared to the standards, raising critical environmental and public health concerns that cannot be ignored. These findings make chromium as a primary contaminant of concern, and highlights the importance of targeted source tracing, as well as standards-based assessment, to determine whether chromium inputs are dominantly anthropogenic, geogenic, or a combination of both. Addressing these findings is crucial to safeguarding both local communities and surrounding ecosystems, as chromium poses serious environmental and health concerns for its toxic, mutagenic and carcinogenic properties (Coetzee and Chirwa, 2020), and has been associated with numerous adverse health effects such as allergies, anemia, and gastrointestinal damage including stomach and intestinal lesions (Hossini *et al.*, 2022) to name a few. In addition, chromium also negatively impacts plant growth by impairing key metabolic processes affecting yield and quality (Sharma *et al.*, 2020).

Cobalt and nickel exceeded guideline values in Stations 1 and 2. This site-specific enrichment may be attributed to the deposition of metal-rich sediments and localized anthropogenic inputs such as agricultural run-off and urban activities.

Copper, lead, manganese, and cadmium concentrations were below the established soil quality standards across all stations. While the values are within acceptable limits according to local regulations, its alignment with other international standards could provide a more robust safeguard against potential environmental and health risks.

Overall trends also indicate that heavy metal concentrations were highest in Station 1, Station 2, and Station 3, respectively. Furthermore, higher heavy metal concentrations at the river site are driven by downhill flow and accumulation of contaminants in low-lying sediments

## CONCLUSION

This research established the baseline soil physicochemical characteristics and heavy metal concentrations in freshwater-influenced sites in Lourdes, Alubijid, Misamis Oriental and compared it with the existing standards. The soil physicochemical properties were largely comparable across stations with no significant differences in pH, electrical conductivity, salinity, total dissolved solids, temperature, or moisture. On the other hand, organic matter was the single parameter that varied, decreasing (from Station 1, Station 2, and Station 3), affecting soil fertility and metal retention. Heavy metal enrichment is observed in areas near the river, notably for Chromium, as it exceeded the established guideline values in all three stations, making it a primary contaminant of concern. The elevated chromium levels in Lourdes, Alubijid may partly reflect geogenic inputs, as the area has been historically associated with past mining activities involving chromium bearing materials. These suggest possible chromium sources in soils and sediments, warranting further geologic and mineralogical investigation. Cobalt and nickel showed strong geographical enrichment in Station 1 and 2, indicating localized contamination possibly due to deposition of metal-rich sediments, and localized anthropogenic inputs. Copper, lead, and cadmium remained within acceptable limits, suggesting no immediate concerns or significant risk. Although manganese levels were also below the standard threshold, continued targeted monitoring is recommended to track whether concentration increases over time or fluctuates with seasonal changes.

## RECOMMENDATIONS

Given the notably high chromium levels observed across all stations, identifying the specific oxidation states present is necessary, as $Cr^{3+}$ and $Cr^{6+}$ differ greatly in toxicity and mobility. Chromium speciation in soils near the river, waterfalls, and creek would allow a more accurate assessment of ecological and health risks, as well as guide remediation efforts when needed.

A systematic monitoring program that measures both physicochemical parameters and heavy metals with additional sampling coverage across locations and across seasons combined with multivariate analyses is recommended. This will provide a more representative and reliable assessment of soil conditions in the area as well as help identify potential relationships between soil properties and metal mobility.

A formal ecological and human health risk assessment including bioavailability tests can better evaluate whether the detected metal levels pose risks to crops, groundwater, or local communities.

Geological assessment, sediment tracing, and land-use mapping are recommended to determine whether elevated metal levels originate from natural ultramafic formations, agricultural activities, or other human inputs.

Exploring appropriate remediation strategies particularly phytoremediation can help reduce the elevated heavy metal levels identified in the study area. Phytoremediation offers a sustainable and cost-effective approach by using metal-accumulating plants to extract, stabilize, or immobilize contaminants, supporting long-term soil recovery and risk reduction. It is also recommended to identify native or locally adapted plant species with high uptake of chromium, cobalt, and nickel.

Awareness campaigns and coordination with LGUs can help ensure proper land management, pollution prevention, and monitoring compliance.

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