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Cobalt Content in Mine Tailing Areas in Bato-Bato, Narra Palawan, Philippines

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Mining is always associated with deforestation and destruction of forest and agricultural land. Though it offers employment and governments' income, it still causes detrimental effects to the environment. The re-opening of open-pit mining corporation in 2011, in the small village of Bato-Bato, Narra, Palawan Philippines aggravated deforestation, floods, and decreased in rice yield of rice farmers. This study determined the Cobalt content in topsoil in mine-tailing sites within the rice farms. Field data collection and laboratory analysis methods were used in this study. This study utilized three sampling sites and three replications per site and 2 kg of topsoil from each replication per sampling site were collected following the quadrant method. The soil samples were sent to the laboratory for analysis. Cobalt content in topsoil was analyzed using Xray Flourescence (XRF) method. Normality of data was determined by Pearson Coefficient of Skewness (PCS) Test. Significant difference on the Cobalt content in topsoil was analyzed using F- Test and appropriate post hoc test. The Cobalt content in topsoil in three sampling sites is high (from 146.7 mg/kg to 306.7 mg/kg) in comparison with the average Cobalt content a topsoil should contain (41 mg/kg). High Cobalt content affects rice productivity. Mining operator should prioritize projects that prevent leaching of mining sediments during flood.

1. Introduction

The most diverse ecosystem is the rainforest. Once a forest is already open for mining, deforestation follows, thereby destroying the ecosystem. Thonfield et al. (2020) stated that forest land cover loss is primarily cause by mining activities in tropical regions. Deforestation of tropical rainforest related to mining destroys carbon storage which is an implication of climate stability. Research on determining heavy metal accumulation such as Cobalt, in mine-tailing sites is gaining popularity among scientists, environmentalists, and environmental planners. This type of research allows one to analyze heavy metals like Cobalt in the soil, since this is a predicted factor in crop growth which can be magnified in the food chain. Cobalt is classified as a transition element. According to Srivastava et al. (2022), Cobalt is a trace mineral in soil and abundant in the earth's crust. Since soil acts as a medium of plant growth the presence of Cobalt in soil has a role in the metabolism of plant. Cobalt is an essential micronutrient for plant growth. Hu et al. (2021) stated the role of Cobalt as a core element in vitamin B12 and its derivatives is vital in plant growth. It also serves as a cofactor on a wider range of enzymes and component of protein in prokaryotic organisms like plants. Anything that is in excess has detrimental effects. Kosiorek and Wyszkowski (2019) posited that retardation on the growth of plant roots and shoots can be attributed to excessive concentrations of Cobalt. Baneerje and Bhataccharya (2021) revealed that 41 mg/kg is the average Cobalt content in soils. However, it can surge as high as 106.44 mg/kg in contaminated soil.
Palawan is an island province of the Philippines (Figure 1). It is home for 17 Key Biodiversity Areas, watersheds, endemic flora and fauna, indigenous tribes and two world heritage sites Palawan is declared as the Philippines last ecological frontier and having rich mineral deposits. Since 2011, A clash between biodiversity and mining prevails in the province. The small village of Bato-Bato is found in the village of Princess Urduja in the Narra Palawan, Philippines (Figure 2). The visible environmental impacts of the mining corporation are loss of wildlife and agro-diversity due to deforestation, food insecurity due to low crop harvest, destruction of the landscape, contaminates the soil due to mine waste leaching, pollution of surface water, ground water depletion, decrease water quality (physico-chemical and biological). The potential environmental impacts are soil erosion, floods,

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and air pollution (Environment Justice Atlas (2015). Palawan experienced strong typhoons and flooding on November 6, 2021. Flooding due to deforestation in mining sites and low-pressure areas happened last March 29, 2022, and another flooding on October 31, 2023 (Palawan News, 2023). Heavy rains and floods are the major factors of heavy metals leaching from mining sites and siltation ponds. Irrigated agricultural lands serve as reservoirs of the siltation from the mining sites. Calleja (2012) reported that on November 25, 2012, the mining corporation failed to control the silt-laden water spilled from its silt pond. The water from the pond overflowed into the "Pinagduguan" river and irrigation canals, affecting 70 rice farms and fishponds. Notice of violation was issued by the Department of Environment and Natural Resources. The mining management constructed Gabions at the gullies and additional silt traps to restrict surface water run-off. Farmers near mining sites are always beset by the problem of low crop yield. Fabro (2020) interviewed a farmer whose farm is near the mining corporation in Narra, Palawan. The rice farmer revealed that his rice harvest decreased from 500 t/km^2 to 225 t/km^2 since the opening of open-pit mining corporation in the area. The farming community has been experiencing low crop yield, as the government lifted the ban for operating an open-pit mining in 2011.

Since the re-opening of open-pit mining in Bato-Bato Narra, Palawan Philippines no study on determining the Cobalt content in soil in mine- tailing areas are conducted. Thus, this study will serve as baseline information and will help environmental planners to come up with programs/projects that will prevent environmental degradation. The study's objective is to determine the Cobalt content in the topsoil in mine-tailing areas and to determine the difference on the Cobalt content in the topsoil in sampling sites in mine-tailing areas in comparison with the average Cobalt content a topsoil should contain.

Figure 1: Coordinates of Narra Palawan Philippines

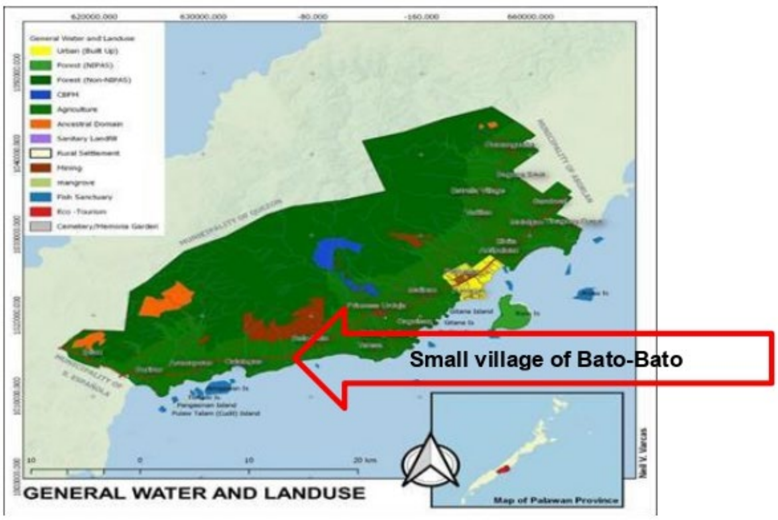

Figure 2: Location of Bato-Bato, Narra Palawan, Philippines in the municipality's general water and land use map

2. Methods

Data collection in the field and laboratory analysis methods were employed in this study. Sampling sites were identified by the licensed Agriculturist from the Municipal Agriculture Office and Licensed environmental planners from the Municipal Planning and Development Office. Global Positioning System (GPS) map camera mobile application was used to determine the coordinates of the three areas for sampling collection. The first sampling site is found in 9.187470 latitude and 118.262792 longitude (Figure 3). For the second sampling site, latitude is 9.183515 and longitude of 118.273770 (Figure 3). Third sampling site coordinates are latitude is 9.183299 and longitude is 118.273962 (Figure 3). Field data collection involved gathering of topsoil from three sampling sites (replicated thrice per sampling site) in mine-tailing areas in Bato-Bato, Narra, Palawan. The quadrant method was used in collecting soil samples per replication per sampling site based on the study of Prematuri et al., 2020. In each site, three plots (2 m × 2 m) were randomly selected and 2 kg of soil samples per replication per sampling site were gathered. Impurities such as stones, roots and litter were removed, and packed in polyethylene and labelled ziplocked bags. The soil samples were sent to the laboratory. Cobalt content in soil samples was analyzed using Xray Flourescence (XRF) method. Margui et al., (2022) explained that XRF is an important analysis method for environmental analysis, research and development of materials and products, since it entails simple sample preparation, and the analysis accuracy is high. Analysis of the data gathered was done using Pearson Coefficient of Skewness (PCS) to determine the normality of data obtained on Cobalt content in topsoil per replicate/sampling site. The formula for PCS is 3 (Mean-Median/standard deviation). PCS value within the range of -2 and +2 denotes normal data. F-test or ANOVA was utilized to determine the significant difference of Cobalt content in the sampling areas. It was computed in Microsoft excel 2019. Significant difference among paired means in ANOVA was computed using Tukey's Honestly Significant Difference (THSD) test.

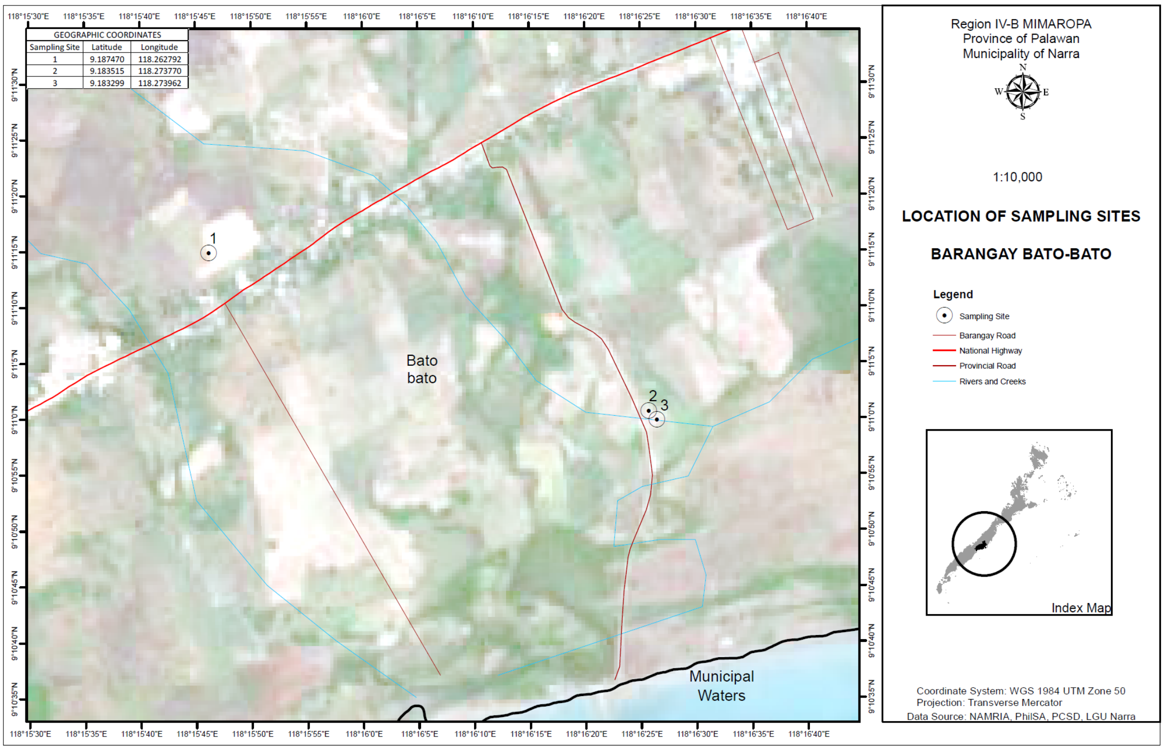

Figure 3: Geotagged map of sampling sites in Bato-Bato, Narra, Palawan, Philippines

3. Results and Discussion

3.1 Cobalt Content in Topsoil in mg/kg.

Table 1 posited the Cobalt content (mg/kg) in topsoil in mine-tailing sites. Sampling site 1 had the highest mean (*M*) Cobalt content in mg/kg (306.7) with a standard deviation (*SD*) of 5.8. Sampling site 3 (*M*=246.7, *SD*=11.5) followed, and the lowest Cobalt content in soil was found in sampling site 2 (*M*= 146., *SD*=11.5). Figure 4 displays the location of the mining site and the three sampling sites. It showed that the first site (approximately 5,000 m) is much nearer to the mining site compared with sites 2 and 3. The three sites are adjacent to the river (blue line in Figure 3) that runs along the rice fields from the mine site to the rice fields. The study of Baneerje and Bhataccharya (2021) stated that the average Cobalt content in soil, is 41 mg/kg. The result of the laboratory analysis in this study showed that the soil in the three sampling sites (1, 2 and 3) is beyond what the average soil should contain. This could be attributed to the flooding in the area which transported the mining sediments including Cobalt in the rice farms. Pascal's Principle (water seeks its own level) prevails in the drainage canals, during floods, and leaching of mining sediments were channeled to the rice farm. The presence of water during floods contributed to the faster mobility of Cobalt in topsoil and readily absorbed by the plants in the area. Lwalaba et al. (2020) stated that due to the high mobility of Cobalt, it is readily absorbed and moved in the entire body of the plant, which lead to toxicity, resulting to stunted growth and chlorotic leaves. Photosynthetic activity is affected by the appearance of chlorotic leaves, which ultimately affects the crop yield. Further, the study explained that the property of Cobalt which binds with thiol groups (-SH) since it combines well with the compounds sulfydryl, can lead to depletion of glutathione (GSH) and lowering its nature to scavenge. Too much accumulation of Cobalt affected the rice physiological processes and the harvest, resulting to financial loss to the farmer. The outcome of Cobalt toxicity on the affected farms in the small village of Bato-Bato Narra, Palawan can be attested by the interview of Fabro (2020) with a farmer. The farmer complained about the reduced rice harvest per cropping season. Rice harvest was reduced from 5,000 kg. per 0.01 $km,^2$ to 2,250 kg/0.01 $km,^2$ since the open pit mining re-opened in 2011. The Cobalt from mine sites which was leached to the rice farm had greatly affected the rice harvest. Wastewater that is untreated carries substantial concentration of heavy metals and is a potential ecological risk to the environment, soil fertility, sustainable agriculture and of course food quality and quantity.

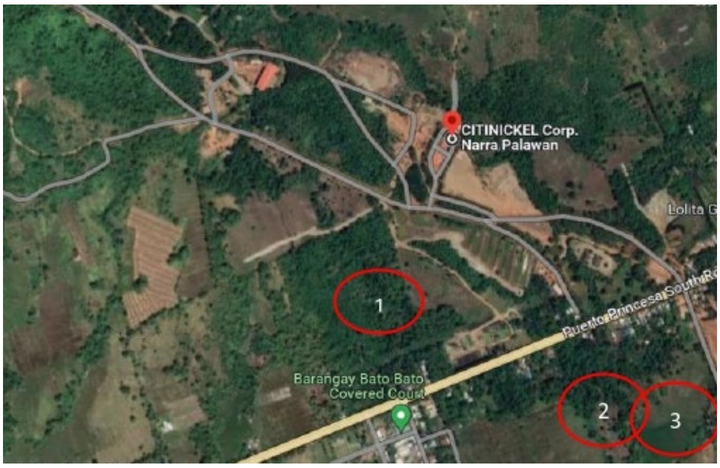

Figure 4: Location of Mining site and sampling sites, 1,2,3 in Bato-Bato, Narra, Palawan, Philippines

Table 1: Cobalt content (mg/kg) in topsoil in mine-tailing sites

Citeria	Control	Cobalt content in mg/kg in three sampling sites		
	Average Cobalt content in topsoil (Baneerje and Bhataccharya, 2021)	Site 1	Site 2	Site 3
Replication 1	41	310	140	260
Replication 2	41	300	140	240
Replication 3	41	310	160	240
Total	123	920	440	740
Mean	41^a	306.7^b	146.7^c	246.7^d
Median	41	310	140	240
Standard deviation	0	5.8	11.5	11.5
Pearson Coefficient of Skewness		1.7	1.56	1.75

Legend: a, b, c, d denotes significant differences exist among treatment means

3.2 Significant difference on the Cobalt content (mg/kg) in topsoil in mine-tailing sites

PCS revealed a negative significant skewness of data (Table 1) which denotes that the data is normally distributed; thus, ANOVA (Table 2), was used to determine significant difference on the Cobalt content in three sampling sites replicated thrice per site. Significant difference (p value. 1.38925-^{09}<.05) was obtained in the ANOVA. Different superscripts denote significant differences among each means. Sunaratiya et al. (2022) reported that Cobalt toxicity in plants is not common in natural soil. However, Cobalt toxicity in plants is caused primarily in contaminated soil due to mining, smelting, disposal of sewage sludge and use of chemical fertilizer. Too much Cobalt in soil affects morpho-physiological processes in plants. Increase concentration of Cobalt lowers the percentage seed germination, decreases growth of root and shoots, and phenolic contents in *Vicia faba*. The study of Roychoudhurry and Chakraborty (2021) also explains Cobalt toxicity in plants. Plants require only 1-2 mg./kg of Cobalt in topsoil. Mahey et al. (2020) reported that too much Cobalt is toxic to plants. Toxic effects include distortion on the structure and physiological process of the leaves, premature leaf closure and decrease shoot biomass, affecting its entire morphology and physiology and crop yield. The study of Gopal et al. (2007) on Cobalt toxicity in tomatoes posited that high accumulation of Cobalt is present in the roots and old leaves and less in the stem. Roots and leaves play a vital role in plant yield. Prominent symptoms of Cobalt toxicity are present on the leaves. Chlorosis is the first symptoms and later scorching, causing leaf distortion.

Regarding the result of THSD test (Table 3), comparison of Cobalt content per sampling site denotes significant result. The presence of Cobalt in first site, second site, third sites are higher compared with the average Cobalt content in soil reported by Baneerje and Bhataccharya, (2021) which should only be 41 mg/kg. It revealed significant difference on the Cobalt content (in three sampling sites) where different superscripts ([a, b, c, d]) in each treatment mean, in Table 1 was posited. Despite the proximity of sampling site 1 to the mining site, the significant difference on the Analysis of Variance revealed that Cobalt content in sampling site 1 did not outnumber sampling sites 2 and 3, thus the amount of Cobalt per sampling site differs from one another. Toxicity of plants to Cobalt starts at 100 mg/ml of capillary water. When Cobalt is carried on by water from the contaminated soil, plant toxicity increases. Irrigated agricultural lands serve as reservoir of the siltation from the mining site. In this study heavy rains and floods are the major factors of Cobalt leaching from mining sites and siltation ponds and thereby leach to lowland areas which mostly consist of rice farms. Somarin (2014) mentioned that mining damages the landscape, contaminating bodies of water and land areas. It creates sediments containing heavy metals and remain in the surrounding soil which are carried by water and wind. Heavy metals from mining sites are non-biodegradable and contaminate the soil. Thus, the soil fertility of agricultural lands in Bato-Bato, Narra, Palawan is greatly affected, thereby lowering the harvest of rice farmers.

Table 2: Analysis of Variance (ANOVA) on the Cobalt content in Soil

Source of Variation	Sum of Squares	Degrees of freedom	Mean Sum of Squares	F	P-value	F critical
Between Groups	122,432.25	3	40,810.75	544.14	1.38925 x 10^{-9*}	4.06
Within Groups	600	8	75			
Total	123,032.25	11				

Legend: * significant at .05 level of significance.

Table 3: Tukey Honestly Significant Difference Test on determining significant difference on the Cobalt content among paired treatment means.

Treatments pair	Tukey HSD Q statistic	Tukey HSD p-value	Tukey HSD inference	Paired means	Analysis
Average Cobalt content (41 mg/kg) vs 2nd site	53.1333	0.0010053	** p<0.01	41 compared with 306.7	Significant difference
Average Cobalt content (41 mg/kg) vs 3rd site	21.1333	0.0010053	** p <0.01	41 compared with 146.7	Significant difference
Average Cobalt content (41 mg/kg) site vs 4th site	41.1333	0.0010053	** p<0.01	41 compared with 246.7	Significant difference
2nd site vs 3rd site	32.0000	0.0010053	** p<0.01	306.7 compared with 146.7	Significant difference
2nd site vs 4th site	12.0000	0.0010053	** p<0.01	306.7 compared with 246.7	Significant difference
3rd site vs 4th site	20.0000	0.0010053	** p<0.01	146.7 compared with 246.7	Significant difference

4. Conclusions

The result of this study showed that high Cobalt content is present in the topsoil in rice farms in Bato-Bato, Narra, Palawan. The Cobalt content in soil is higher (from 146.7 mg/kg to 306.7 mg/kg) than the average Cobalt content in mg/kg (41) a topsoil should contain. Once the Cobalt is leached by floods from deforested mining sites to mine tailing sites it is a factor that reduced crop productivity. Therefore, it is recommended that mining operators should ensure that the silt ponds in their mining sites will prevent the leaching of heavy metals like Cobalt in rice farms. The environmental and agricultural offices of the municipality should monitor closely the activities in the mining site that will harm the environment. It is also recommended that studies on heavy metal profiling in the mining areas should be used in planning for programs related to environmental sustainability of the municipality.

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