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Assessment of heavy metal contamination levels in the soil of the former Poura mine in Burkina Faso (West Africa)

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Abstract

The development of the mining sector in Burkina Faso has its roots in small-scale mining, which has been practiced for many years. However, this activity causes enormous disruption to the environment and threatens the ecosystems around these facilities. The objective of this study is to assess the level of heavy metal contamination in the soil in the area surrounding the former Poura mine. A grid was established for the study site. This grid was tightened to a radius of 600 meters from the ends of each tailing and cyanide tank in the four cardinal directions, taking into account the direction of surface water flow. A distance of 200 meters between sampling points was established. A total of 35 sampling points were identified. Thirteen (13) soil samples were taken from tailings pile 1, eleven (11) from around tailings pile 2, and eleven (11) from the cyanide tank. The results show heterogeneous concentrations of As, Cd, Cr, Cu, Ni, Pb, and Zn in the soil. These vary depending on the metal and the source of pollution. Median manganese concentrations are high in all three sources. Tailings 1 has the highest median with 900 $mg.kg^{-1}$ of Mn, followed by the cyanide tank, while tailings 2 show lower values. With Mn, the dispersion is asymmetrical for the tailings, with the presence of extreme values. However, with regard to arsenic (As), the median concentrations in the various sources are all very close to 0 $mg{\cdot}kg^{-1}$ and do not show any significant difference. The distributions are asymmetrical, particularly for tailings 1 and tailings 2.

Consequently, the soils in the area affected by the Poura mine can be considered poor quality in terms of heavy metal content.

Keywords: Heavy Metals; Cyanide Tank; Tailings; Poura Mine; Burkina Faso

1. Introduction

Since the beginning of the twenty-first century, the first signs of an exacerbation of the negative impacts of mining have been felt in countries south of the Sahara (Cooke and Johnson, 2002) due to the continuous increase in production sites and the use of chemicals such as mercury and cyanide. Agricultural production has therefore been gradually displaced to make way for rugged sites, often contaminated with chemicals that are harmful to ecosystems and human health (Sarwar *et al.*, 2010; Schueler *et al.*, 2011; Abbas *et al.*, 2018). In mining, open-pit mines have the greatest impact on surrounding areas (Lin *et al.*, 2005) because of the large areas occupied by tailings and waste rock. In addition to the

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physical disturbances caused by ore excavation or its piling up over large areas, there are the induced effects of chemicals (both natural and anthropogenic) that pose a major risk to ecosystems.

On the one hand, industrial ore processing methods use chemicals such as cyanide, and the management of residues from these processes requires special attention. In artisanal mining, in addition to cyanide, mercury is also used, even though it is banned in Burkina Faso (DGPE, 2017). On the other hand, chemicals that occur naturally in rocks in stable forms may pose a risk of mobility or bioavailability when exposed to certain disturbances. These include metals and metalloids such as cadmium (Cd), zinc (Zn), iron (Fe), lead (Pb), selenium (Se), and arsenic (As), whose presence varies depending on the rocks present.

Since the closure of the Burkina Mining Research and Development Company (SOREMIB) in Poura, the physical and biological environment of the municipality has long been exposed to environmental disaster and posed an unprecedented public health issue. All waste from the Poura mine has been left in the open without any measures being taken to protect against infiltration and mine drainage. As a result, the mine waste has been constantly exposed to the effects of climatic phenomena and the gold miners who handle it on a daily basis. These waste products are constantly dispersed by water, wind, and human activity (Bouzahzah *et al*., 2014). This situation will obviously lead to heavy metal contamination of the soil in the study area. This study was conducted in response to these concerns. The overall objective of this study is to assess the level of heavy metal contamination in the soil in the area surrounding the former Pourra mine. This concern is all the more justified given that metals have the ability to accumulate in living organisms. In view of these environmental and health problems caused by heavy metals, studies should be carried out to assess the level of soil contamination at the Poura mine.

2. Materials and methods

2.1. Location of the study site

The study site is focused on the former Poura mine. Poura is a rural commune in the Bale province, located southwest of Ouagadougou, 106 miles from the Ouaga-Bobo highway and 27.7 miles from Boromo, the provincial capital. It is located between 11°20′ and 11°50′ north latitude and between 2°40′ and 2°55′ west longitude. The commune of Poura covers an area of 101.81 km^2. A single road (Regional Road RR11) connects Poura to National Road (RN) No. 1.

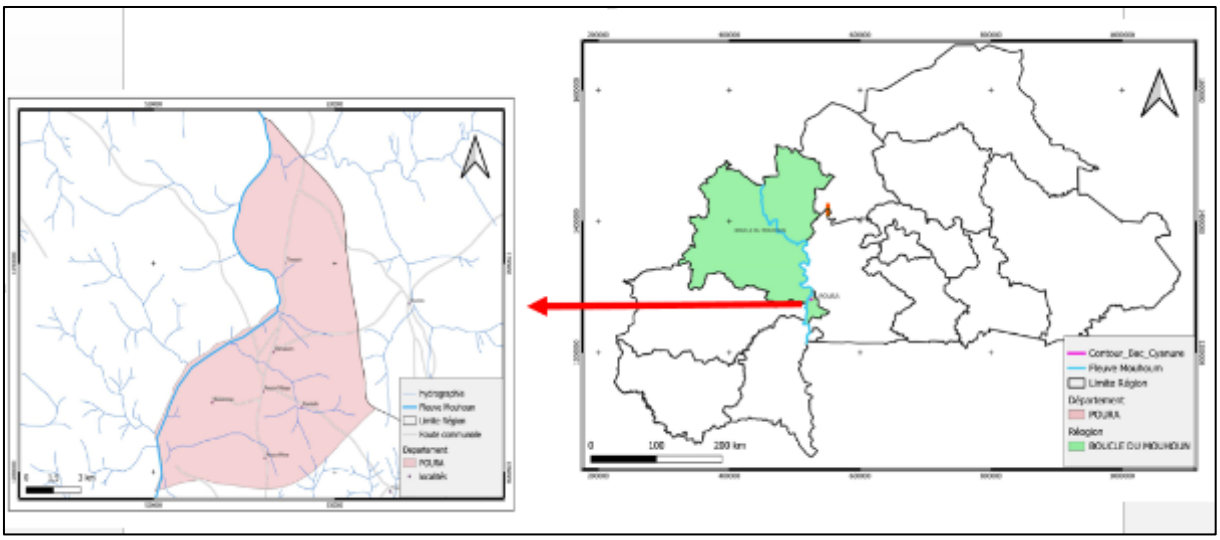

Figure 1 Map showing the location of the study area in the municipality of Poura

2.2. Site grid and soil sampling

As part of the study site grid, we created a dense grid within a 600 meter radius from the ends of each tailings pile and the cyanide tank, following the four cardinal directions and taking into account the direction of surface water flow. A distance of 200 m between sampling points was maintained. A total of 35 sampling points were identified. Thus, 13 soil samples were taken at tailings pile 1, 11 around tailings pile 2, and 11 at the cyanide tank. Samples were taken from a depth of 0 to 30 cm (Abaga, 2012). Figure 2 shows the soil sampling map.

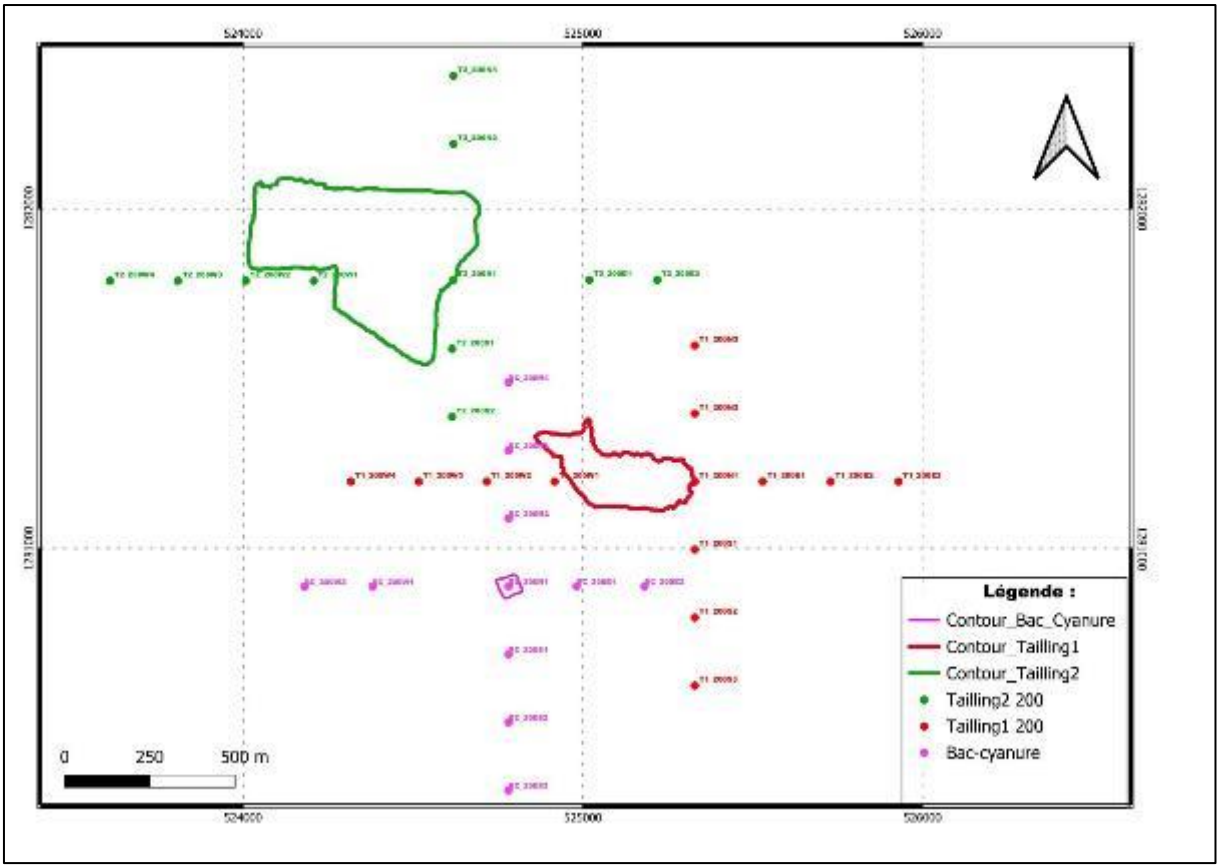

Figure 2 Soil sampling map

The samples were packed in plastic bags and transferred to the laboratory of the Burkina Bureau of Mines and Geology (BUMIGEB) for analysis.

2.3. Heavy metal analysis in soil samples

The samples were dried at ambient temperature, crushed, and sieved through a 125 µm sieve for laboratory analysis. Heavy metal analysis was carried out at the Burkina Faso Bureau of Mines and Geology (BUMIGEB) laboratory in Bobo-Dioulasso in accordance with AFNOR NF ISO 11 460. The samples were mineralized using a hot plate and a mixture of hydrochloric acid and nitric acid. The final solution was analyzed using an Agilent atomic absorption spectrometer (model Varian SpectrAA-240 FS) to measure heavy metal levels. It is equipped with a background noise correction system using a deuterium lamp. The heavy metals measured were chromium (Cr), zinc (Zn), nickel (Ni), copper (Cr), and lead (Pb). Before analyzing the samples, the device was calibrated by selecting the specific wavelength for each metal (357.9 nm for chromium, 324.8 nm for copper, 252.0 nm for nickel, 217.0 nm for lead, and 213.9 nm for zinc).

2.4. Statistical data analysis

The data were entered using Excel 2016 spreadsheet software. R software version 4.3.1 (R Core Team, 2023) was used for data processing. The distribution of heavy metal values in the different samples was checked for normality and homogeneity using Shapiro-Wilk tests. Student's t-tests were used as appropriate to compare the content per horizon; ANOVA and Kruskal-Wallis tests were used as appropriate to compare the variation in parameter content according to horizon. Tukey's post-hoc test was used to compare the means. The results were interpreted at the 5% significance level.

3. Results

3.1. Heavy metal content in soil

3.1.1. Arsenic levels

The arsenic content in the soil samples is shown in Figure 3.

In the cyanide tank, out of the 11 soil samples, only 3 samples, namely N1, N4, and S3, contained arsenic with respective concentrations of 55.1 mg/kg, 25.9 mg/kg and 664.8 mg/kg. In tailings 1, with 13 samples analyzed, 6 samples recorded very high arsenic levels (374.5 mg/kg) at point W4. In tailings 2, out of a total of 11 samples, 4 samples had very high arsenic levels at point N2 (707 mg/kg).

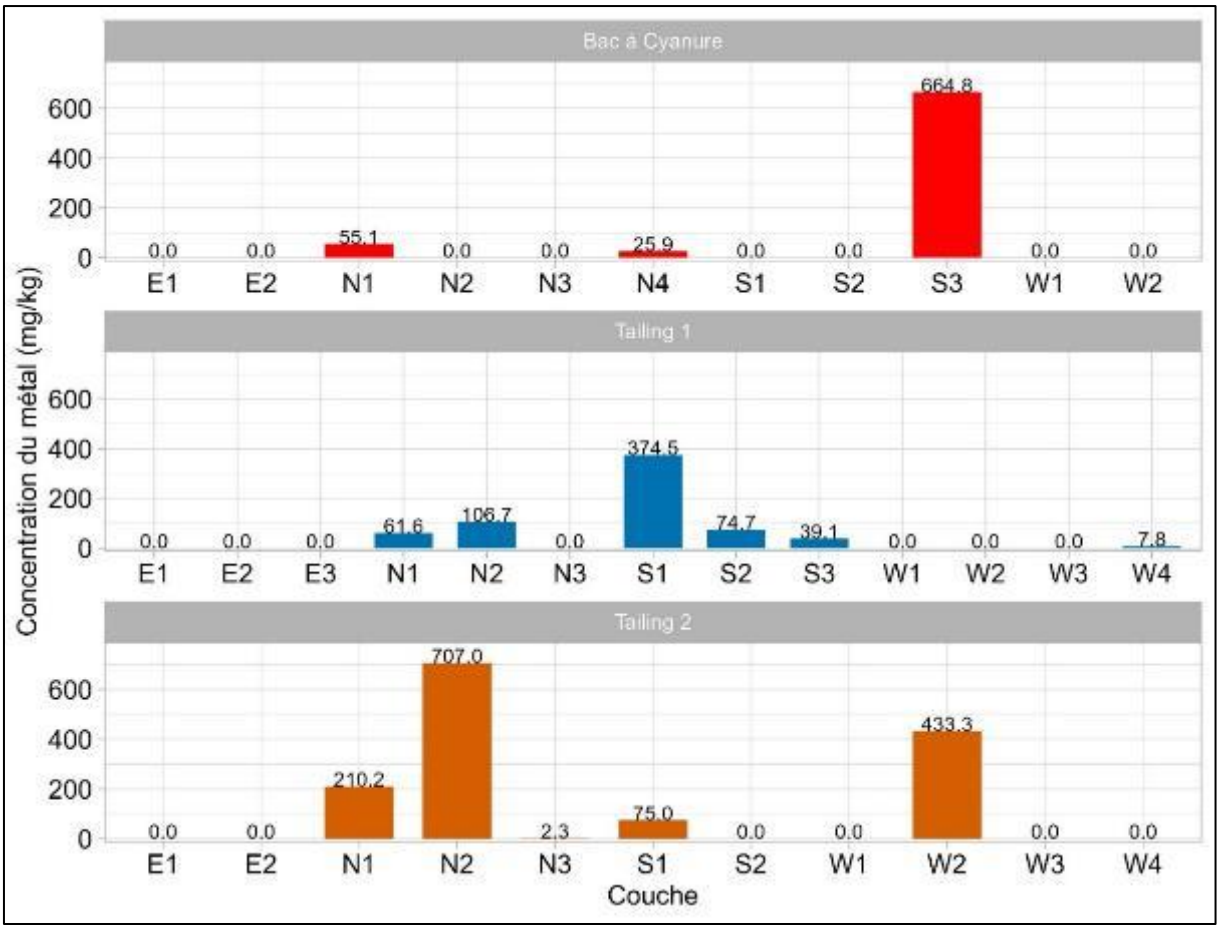

Figure 3 Arsenic content of soil samples

3.1.2. Cadmium levels

The results of the soil sample analysis reveal that, of the 11 samples taken around the cyanide tank and the 13 samples taken at tailings pile 1, only one sample from each of the two sources of pollution contained cadmium. In the cyanide tank, the only cadmium content was observed at point S3, with a concentration of 247.9 mg/kg, and in tailings 1, it was at point E3, with a value of 274.5 mg/kg. The same is true for tailings 2, where out of the 11 samples, only one contained cadmium (point W2) with a value of 224.4 mg/kg. The highest level was recorded in tailings 1 (274.5 mg/kg).

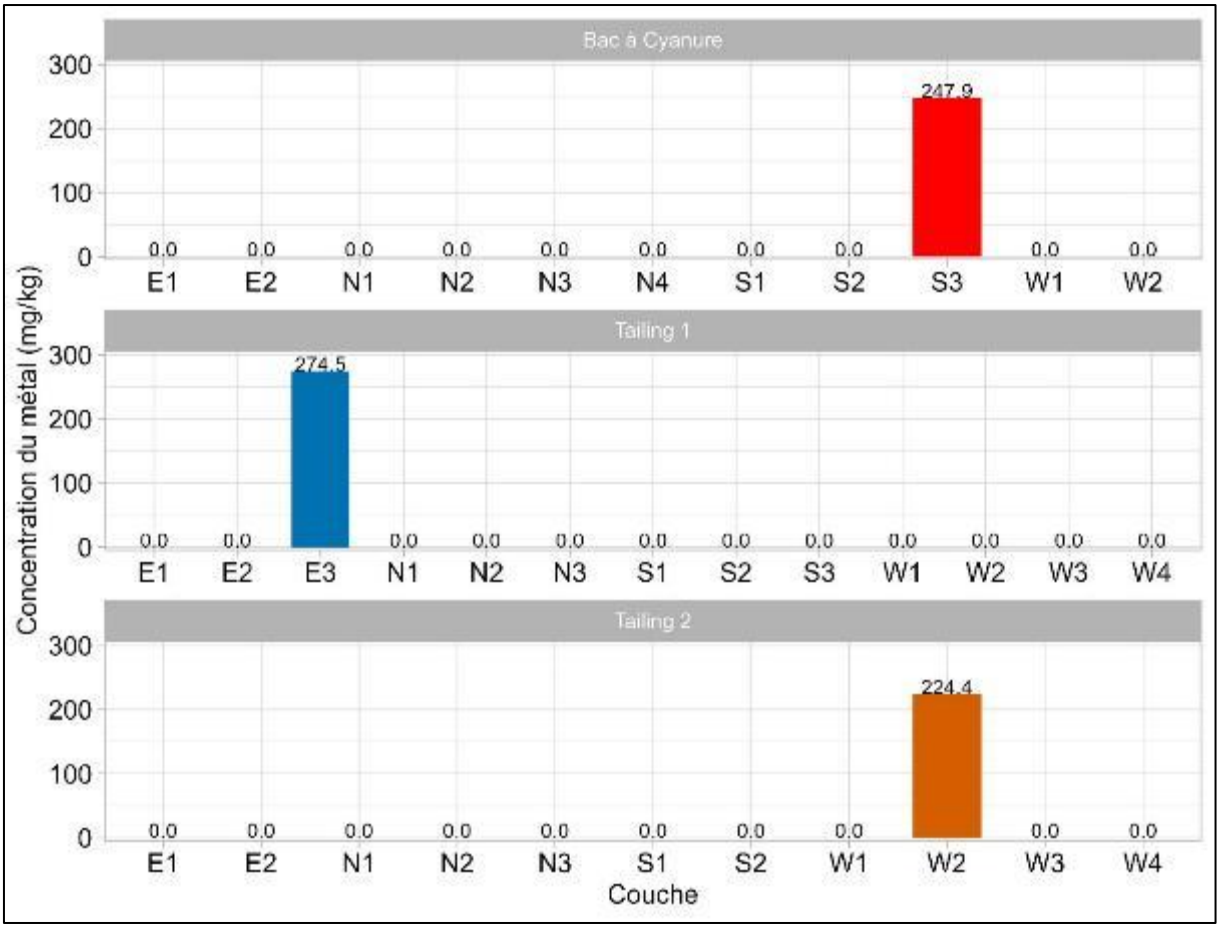

Figure 4 Cadmium content of soil samples

3.1.3. Chromium levels

The results show that in the cyanide tank and tailing 1, all samples contained chromium (Figure 5). The lowest concentration in the cyanide tank was recorded at point S1 with a concentration of 7.1 mg/kg, and the highest concentration of 99.3 mg/kg was observed at point E2. In tailing 1, the lowest concentration was recorded at point S3 with a concentration of 33 mg/kg, and the highest concentration of 110.2 mg/kg was observed at point W1. In tailing 2, apart from point W2, which did not contain chromium, the remaining 10 samples also contained chromium. The highest concentration was observed at point N1 (94 mg/kg), and the lowest, 0.7 mg/kg, at point E1.

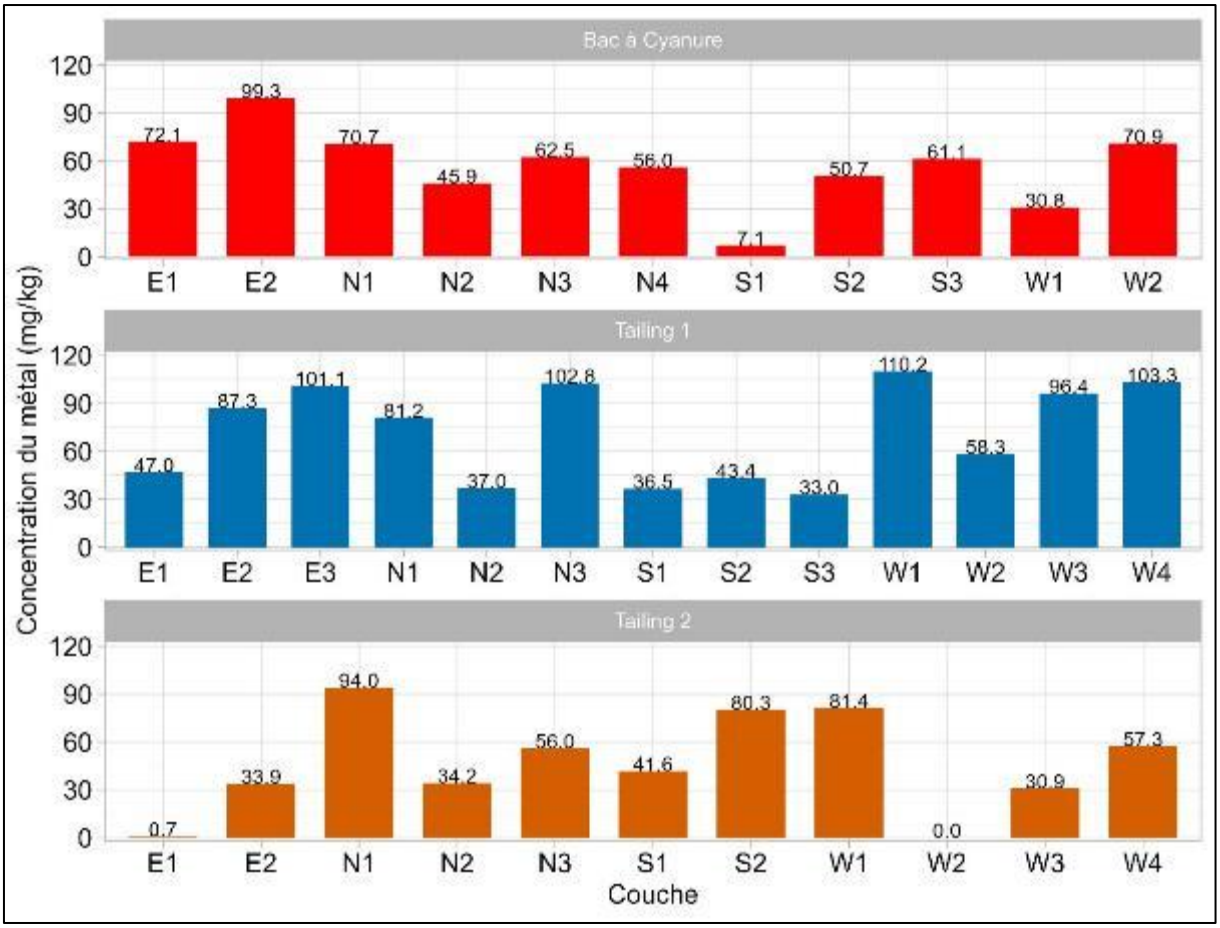

Figure 5 Chromium levels in soil samples

3.1.4. Copper levels

With regard to copper, the results of the analysis of soil samples taken in the study area reveal that all 11 samples from the cyanide tank contain copper (Figure 6). The minimum content was observed at point S1 with 5.6 mg/kg and the maximum of 58 mg/kg was recorded at point E1. In tailings 1, all 13 samples analyzed also contained copper, with the maximum observed at S1 with 70.1 mg/kg. In tailings 2, all 11 samples taken also contain copper. The highest value is given by the sample taken at point W2 with 65.2 mg/kg, while the lowest is recorded at point E1 with 0.1 mg/kg.

Regardless of the source of pollution (cyanide tank, tailings 1 and tailings 2), the soils contain chromium. The highest concentration was 70.1 mg/kg, observed at S1 in the cyanide tank, and the lowest was at point E1 in tailings 2, with a concentration of 0.1 mg/kg.

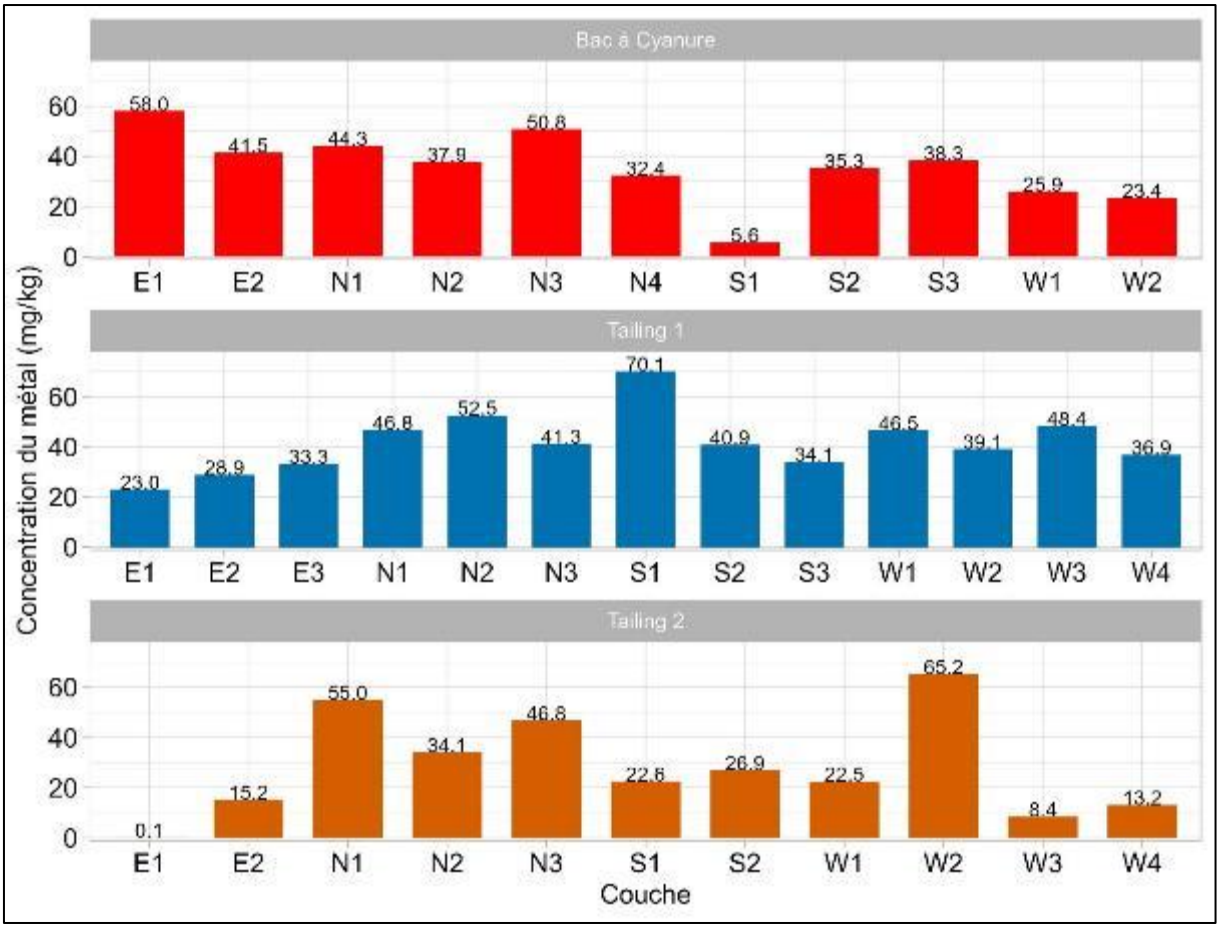

Figure 6 Copper contents of soil samples

3.1.5. Lead levels

The results of the soil sample analysis reveal that, of the 11 samples taken around the cyanide tank and the 13 samples taken around tailings pile 1, only one sample from each of the two sources of pollution contained lead (Figure 7). In the cyanide tank, the content was observed in the sample at point S3 with a concentration of 8.1 mg/kg, and in tailings 1, at point E3 with a value of 2.4 mg/kg. In tailings 2, out of a total of 11 samples, only two samples contain lead. These are points N1 and N2 with 13.2 mg/kg and 11.6 mg/kg, respectively.

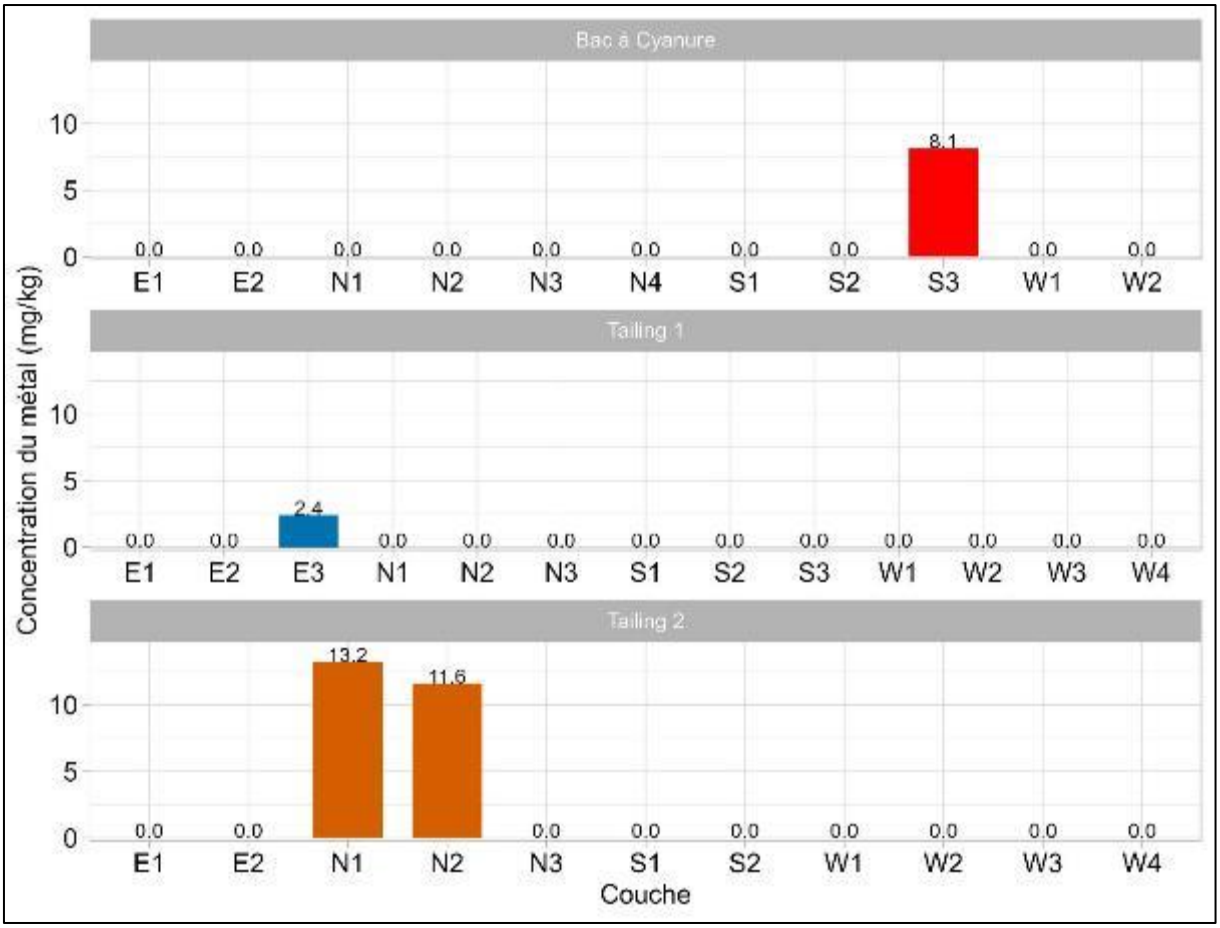

Figure 7 Lead content in soils

3.1.6. Manganese levels

The results of the manganese content of soil samples taken in the study area are shown in Figure 8. It appears that, regardless of the source of pollution, the samples taken contain manganese. In the cyanide tank, the maximum content (11 826.1 mg/kg) is noted at point N3. For tailings 1 and tailings 2, the maximum levels were recorded at points W2 and N1, respectively, with 3429.6 mg/kg and 348.2 mg/kg. In the study area, the lowest lead concentration was observed at point E1 of tailings 2, with a concentration of 5.7 mg/kg.

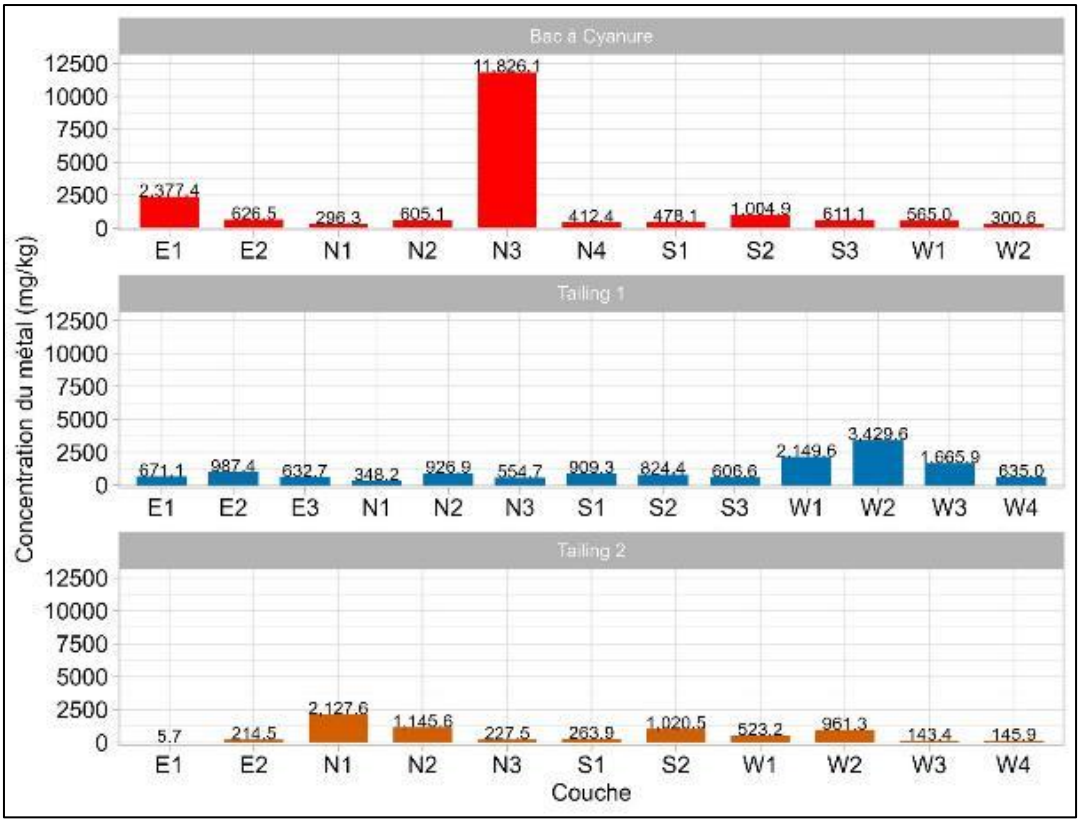

Figure 8 Manganese content of soils

3.1.7. Zinc levels

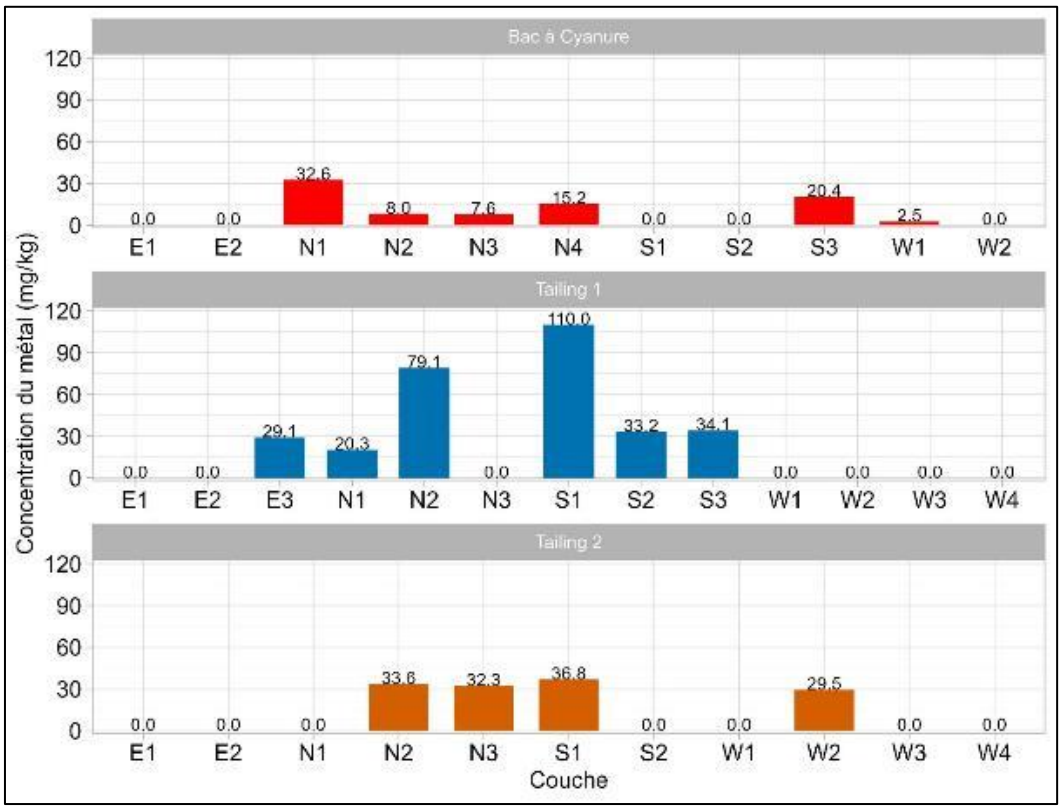

Figure 9 Zinc concentrations in soil samples from the three sources of pollution

The results of zinc content in soil samples from the study area are shown in Figure 9. It appears that in both the cyanide tank and tailings 1, six samples showed zinc content. In the cyanide tank, these levels ranged from 2.5 mg/kg at point W1, considered to be the lowest, to 32.6 mg/kg at point N1, considered to be the highest. In tailings 1, the minimum level was 20.3 mg/kg at point N1 and the maximum was 110 mg/kg at point S1. In tailings 2, out of a total of 11 samples, only 4 samples contain zinc levels. The highest value is recorded at point S1 with a level of 36.8 mg/kg.

3.1.8. Nickel levels

The different concentrations of nickel contained in each sample by pollution source are shown in Figure 10.

The results of the analysis of soil samples taken in the study area reveal that in the cyanide tank and tailings 1, only one point does not show nickel content. These are points S1 and N3 in the cyanide tank and tailings 1, respectively. In tailings 2, all samples contained nickel, with a maximum at point W2 (46.5 mg/kg). The highest concentration recorded on the site was observed in the cyanide tank at point N3, with 81.8 mg/kg.

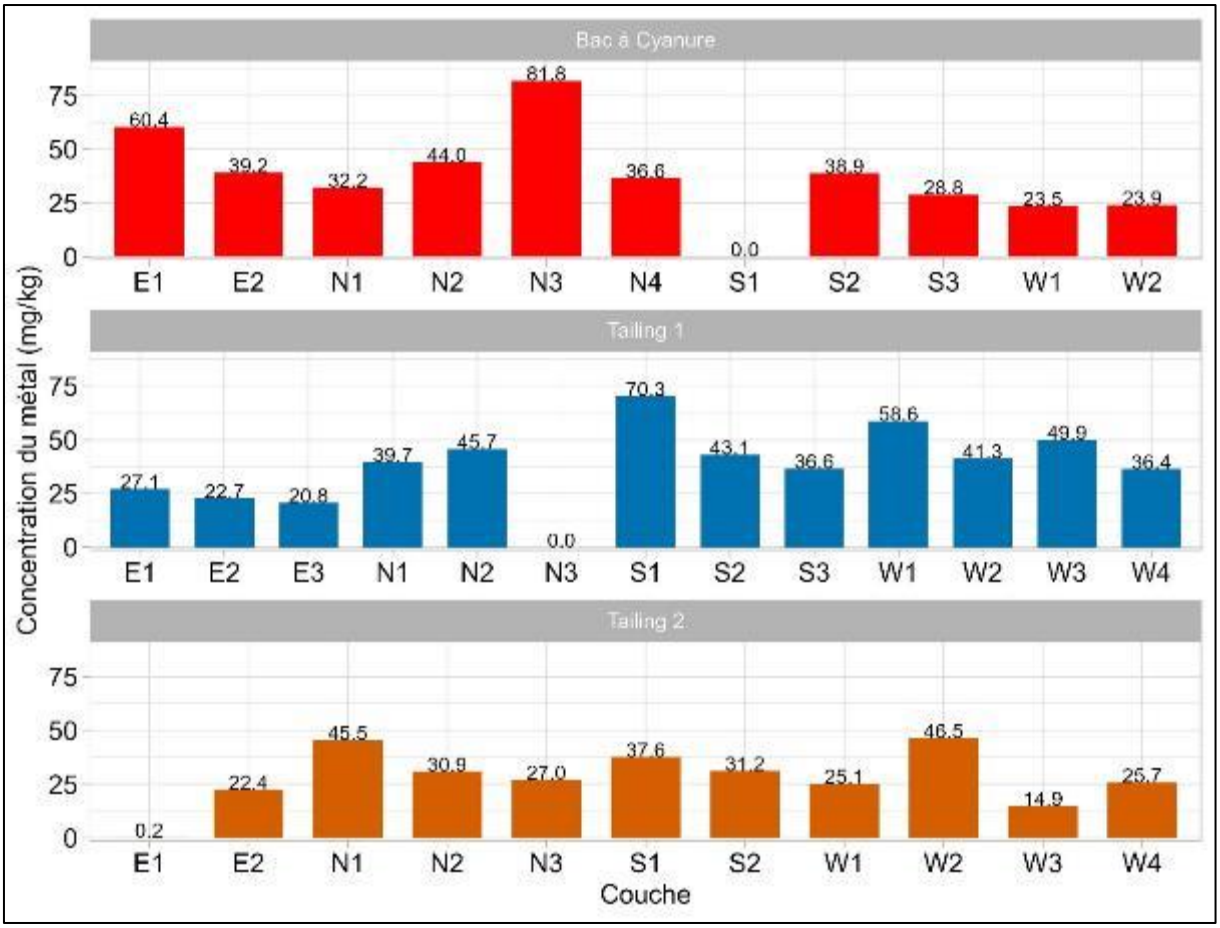

Figure 10 Nickel content of soil samples

3.2. Comparison of heavy metal concentrations in surface soils

Figures 11 and 12 show a comparison of heavy metal concentrations in soil samples taken from the three sources of pollution, namely the cyanide tank, tailings 1, and tailings 2.

The average concentrations of As, Cd, Cr, Cu, Mn, Ni, Pb, and Zn in the cyanide tank and tailings 1 and 2 are illustrated in Figure 11. The color scale of this heat map has been normalized by metal from 0 to 1 for chromatic comparison. Thus, tailings 2 are the least contaminated, with only two (02) metals (As and Pb) falling between 0.75 and 1 on the scale. Tailing 2 is the cyanide tank with four metals (Cu, Ni, Cd, and Mn) that fall between 0.5 and 1 on the scale. This last source is followed by tailing 1, which has four (04) metals (Cr, Cu, Ni, and Zn) with a scale between 0.75 and 1.

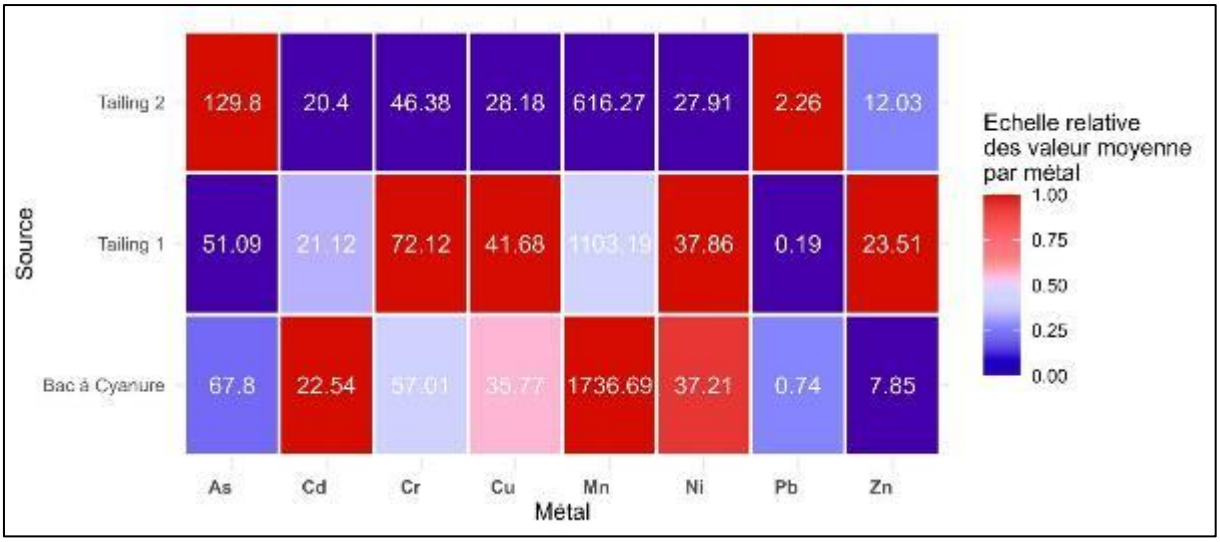

Figure 11 Map of average heavy metal concentrations measured in the cyanide tank, tailings 1 and 2

The concentrations of heavy metals in the different sources are shown in Figure 12. For arsenic (As), the median concentrations in the different sources are all very close to 0 $mg \cdot kg^{-1}$ and show no significant difference. The distributions are asymmetrical, particularly for tailings 1 and tailings 2.

For cadmium (Cd), the median concentrations are also close to 0 $mg \cdot kg^{-1}$, with no significant differences between the three sources. As with As and Cd, chromium (Cr) concentrations differ between sources, with median values ranging from 80 to 100 $mg \cdot kg^{-1}$, for tailings 2 and tailings 1, respectively.

For copper (Cu), the distributions are moderately dispersed, with the lowest median concentration (20 $mg \cdot kg^{-1}$) observed in tailings 2 and the highest (35 $mg \cdot kg^{-1}$) in tailings 1.

For manganese (Mn), median concentrations are high in all three sources. Tailing 1 has the highest median at 900 $mg \cdot kg^{-1}$, followed by the cyanide tank, while tailing 2 shows lower values. The dispersion is asymmetrical for tailings, with the presence of extreme values.

In terms of nickel (Ni), the distribution of concentrations is relatively narrow. The medians are similar between the cyanide tank and tailings 1 (40 mg/kg), while tailings 2 has a slightly lower median, suggesting a moderate difference between this source and the other two.

For lead (Pb), the median concentrations are close to 0 $mg \cdot kg^{-1}$ and similar between the three sources, although a few higher outliers are observed, particularly in the tailings.

Zinc (Zn) shows high variability in concentrations. The medians are higher in tailings 1 and 2, at 23,51 and 12,03 $mg \cdot kg^{-1}$, respectively. In contrast, the cyanide tank has the lowest value (7.85 $mg \cdot kg^{-1}$).

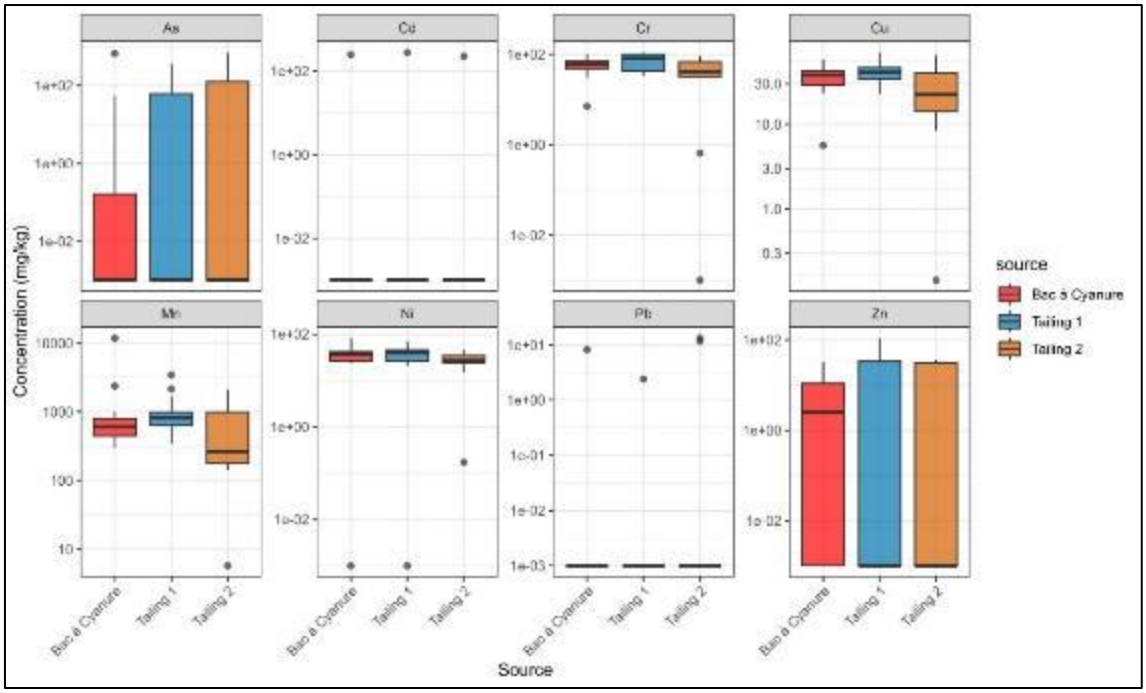

Figure 12 Comparison of the levels of each heavy metal by source of pollution

3.3. Degree of pollution of samples

The dispersion of samples according to their heavy metal content is shown in Figure 13. It shows a fairly heterogeneous distribution of the degree of pollution in the study area. The eastern part of the study area is marked by severe and significant pollution points. Only point N3 of tailings 2 in this part shows moderate pollution. The central and western parts of the area show points with low to significant pollution levels.

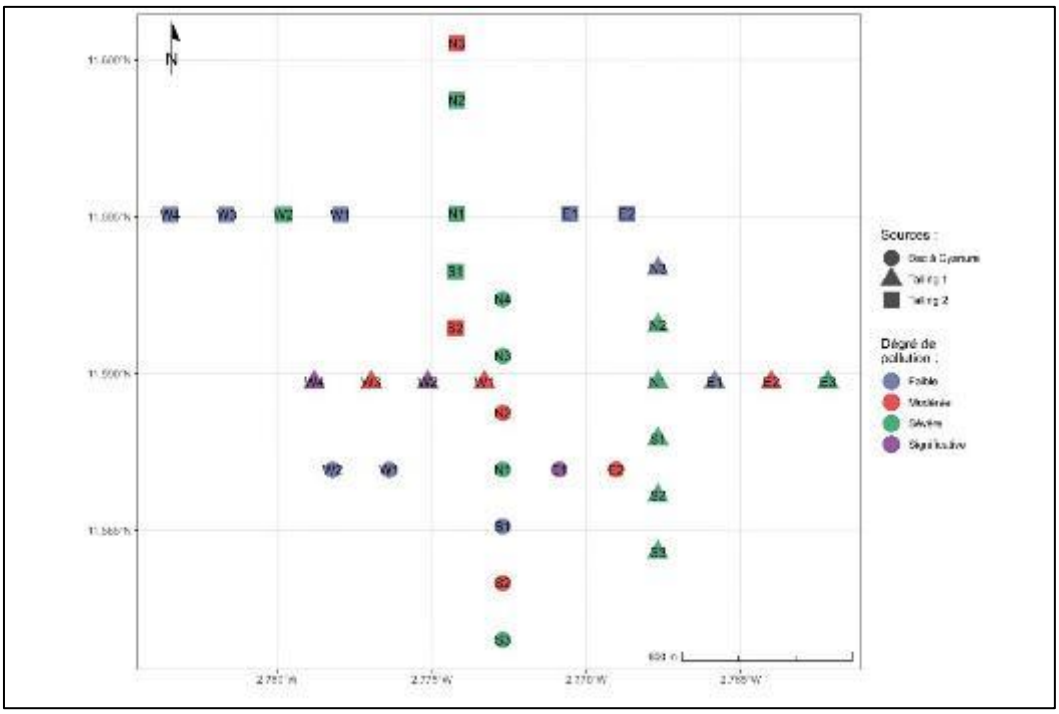

Figure 13 Dispersion of samples in the study area according to ETM content

The number of samples per pollution level is shown in Figure 14.

Taking into account the number of samples taken in the study area and the number of metals measured per soil sample, a total of 280 metal elements were analysed. The results show that 210 of the 280 metal elements have a lower content than so-called polluted soils. In addition, 46 elements have slightly polluted soil levels and 8 have moderately polluted soil levels. On the other hand, 2 elements have highly polluted soil levels and 3 have highly to extremely polluted soil levels. Eleven (11) elements have extremely polluted soil levels.

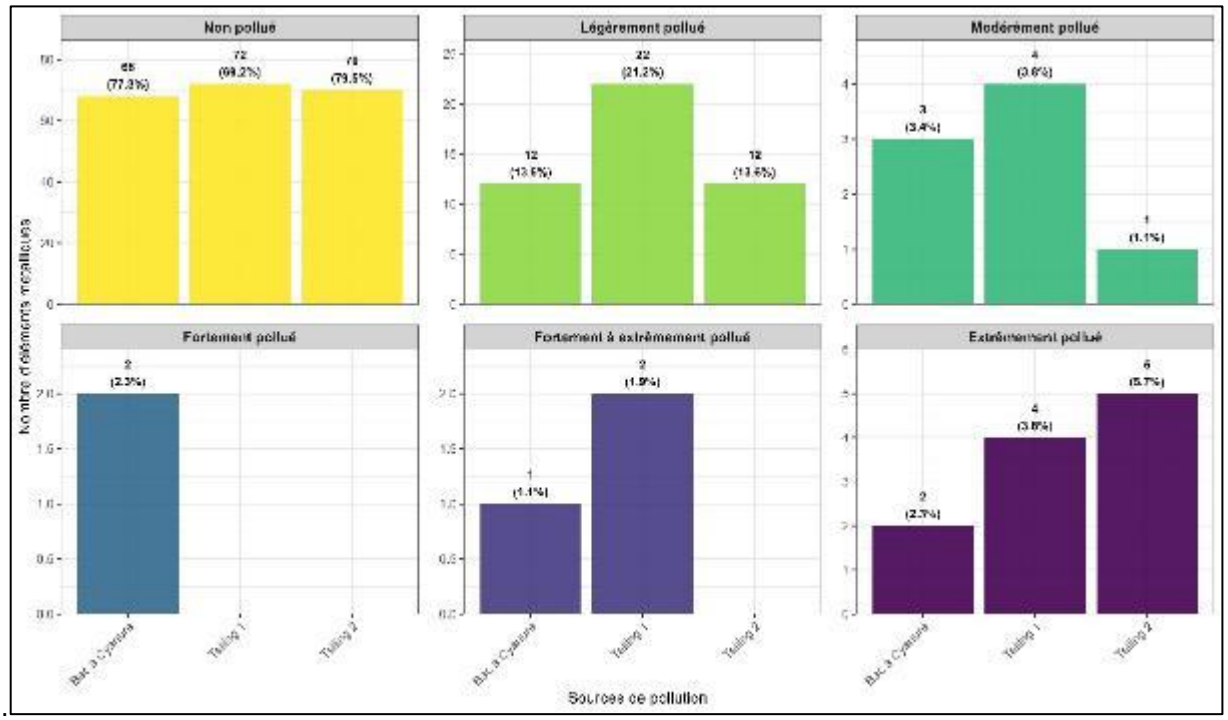

Figure 14 Number of metal elements measured and level of pollution

4. Discussion

The results highlight the presence of several areas of high concentrations around each source. Around the cyanide tank, there is a point to the south, point S3, where heavy metal concentrations are very high. This point corresponds to a sample taken 600 m south of the cyanide tank, suggesting a potential migration of heavy metals to the south. This migration could be explained by surface runoff along the slope or via effluent flow. On the Tailing 1 side, the most contaminated point is located to the east. This point, labelled E3, is located 600 m east of the tailings pond. This may indicate that heavy metals from Tailing 1 are dispersing preferentially towards the east. A likely reason could be the local topography or prevailing winds. These results corroborate those found by Langunu (2025), who also highlighted the dispersion of mining metal pollutants depending on wind and rainwater.

This author also demonstrated that the direction of rainwater flow plays a major role in the leaching and drainage of mining metal pollutants. Very high concentrations were also observed at point S1, located 200 m south of tailings 1, indicating very high contamination 200 m to the south, which suggests another hot spot in this direction. With regard to Tailing 2, there are points where levels are high. The first, point W2, is located west of Tailing 2 and the second, N2, is located to the north. This situation could also be explained by the dispersion of heavy metals from Tailing 2 via dust transport or leaching (Duodu *et al*., 2016) to a ravine to the north. On the other hand, some areas closer to the sources show significantly lower pollution values, illustrating the spatial heterogeneity of contamination in the study area. These areas of high contamination could result from micro-relief (depressions concentrate polluted sediments), the nature of the waste (areas richer in metal sulphides), or past mining practices (orientation of settling ponds, accidental spills) (Adje *et al*., 2021).

The results show that each of the three sources contributes to contamination of the study area, with irregular spatial gradients (Reible, 2014) and specific critical zones.

5. Conclusion

The soils of former abandoned mining sites, if not properly maintained or rehabilitated, become dangerous sources of environmental pollution. Indeed, the chemicals (cyanide, acids, peroxide, etc.) used in mining operations, and especially in various mine tailings, can, under the influence of climatic (air and rain) and human activity, lead to the leaching of various mining pollutants (cyanide and heavy metals). This leaching can generate acid mine drainage (AMD) and contaminate soils, water, vegetation, and the ecosystem in general. This study demonstrates that, despite several decades since its closure, the soils of the Poura mining site still contain trace metals that far exceed international standards. In view of the environmental impacts that mining pollutants can generate, it is important and even very urgent to find ways and means, especially in the long term, to clean up abandoned mining sites and those currently in operation (progressive rehabilitation).

Compliance with ethical standards

Disclosure of conflict of interest

The authors of this article declare that there is no conflict of interest.

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