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Migration of heavymetals in the upper horizons of miningsoil : the case of the former Poura mine (Burkina Faso)

ABSTRACT

The presence of contaminants in an environment and their mobility depend greatly on the nature of the environment, climatic and geological conditions, and anthropogenic influences. Soil contamination by these heavy metals poses a significant public health risk due to the various diseases they can cause. The objective of this study was to examine the migration of heavy metals through their concentrations in the upper horizons of a mining soil. Soil profiles were taken between the two piles of mining waste known as tailings 1 and tailings 2, as well as between these tailings and a cyanide tank, all located on the mine site. The soil profiles had four layers or horizons identified by color. The dimensions were 1,5 m deep, 0,90 m wide, and 1,5 m high. The results show that profile 1 was generally the least contaminated with metals. Cadmium (Cd) stands out due to its accumulation in profile 2 (74,07 mg/kg). Arsenic (As) has very low levels in all profiles. It is practically zero in profiles 1 and 2, while a low average value of 0,33 mg/kg is observed in profile 3. Chromium (Cr) concentrations are high in all three profiles, with 87,62 mg/kg in profile 1, 134,09 mg/kg in pit 2, and 133,88 mg/kg in profile 3. Zinc (Zn) levels are very low in all profiles, with a measurable value only in profile 2 (0,09 mg/kg). Manganese (Mn) is the predominant metal. Its concentrations increase sharply from profile 1 (713,17 mg/kg) to profile 2 (1689,11 mg/kg), reaching a maximum in profile 3 (7349,53 mg/kg). Nickel (Ni) follows an increasing gradient, with 21,51 mg/kg in profile 1, 26,27 mg/kg in profile 2, and 185,22 mg/kg in profile 3. Lead (Pb) remains low overall, with no presence in profile 1, a concentration of 2,68 mg/kg in profile 2, and 0,8 mg/kg in profile 3. These heavy metals (Mn, Ni, Cr, Cu, and As). The contamination hierarchy observed from the heat map was established as follows: profile 3, profile 2, then profile 1. This trend highlights a higher metal accumulation in profile 3, while profile 1 appears to be the least impacted.

Keywords: Heavy metals, migration, soil profile, horizon, Poura mine, Burkina Faso

INTRODUCTION

The recent development of the mining industry in Burkina Faso has led to a considerable increase in gold production, making it the country's leading source of export revenue ahead of cotton. The country's annual gold production rose from 5,8 tons in 2008 to 14 tons in 2009 (SCADD, 2012), reaching 62 tons in 2019 and 74 tons in 2020 (Yao, 2021). This sharp increase in production, resulting from the commissioning of 17 industrial mines over the last decade, has helped Burkina Faso maintain its position as Africa's fifth largest gold producer. In addition to these industrial facilities, there are hundreds of artisanal and semi-industrial operators scattered throughout the country. In 2016, there were already 448 operational artisanal gold production sites spread across all regions of the country except the central region (INSD, 2017). Specifically, in certain precious metal deposits, gold or silver are associated with metalloid elements such as arsenic, which is known for its toxicity in the environment. This arsenic can then be exposed during ore excavation and take on a toxic form, posing a danger to the environment and human health (Matschullat, 2000). In other deposits, the natural oxidation of sulfide minerals in rock when exposed to air and water causes acid mine drainage (AMD), which contributes to various types of pollution. All of these forms of pollution result in reduced access to drinking water, loss of soil fertility, reduced vegetation cover, loss of biodiversity, and habitat fragmentation (Schueler et al., 2011).

This study therefore aims to examine the vertical migration of metals in the soils of a former mine in Burkina Faso. Our specific objectives include analyzing the distribution of heavy metals in soil profile horizons, as well as comparing concentrations between horizons on the one hand and between layers on the other. We will present the methodology in detail, before presenting and discussing the results obtained, and finally making recommendations.

MATERIALS AND METHODS

Location of the study site

The study site is focused on the former Poura mine. Poura is a rural commune in the Balé 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 km². A single road (Regional Road RR11) connects Poura to National Road (RN) N° 1.

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

Soils at the study site

The soils of Poura are mainly tropical ferruginous soils, which are shallow, not very fertile, and susceptible to erosion (Yaméogo et al., 2024). These soils are common in the region and can be classified into several groups.

- Tropical ferruginous soils: located near watercourses, these soils are associated with water conditions and are often used for agriculture.
- Ferralitic soils: found in the provinces of Houet, Kénédougou, Comoé, and Mouhoun, these soils contain clays rich in iron and aluminum.
- Brown soils: located in the western, southwestern, north-central, and northwestern parts of the country, these soils are often used for various crops.
- Raw mineral soils or lithosols: formed directly from bedrock, these soils are often poorly developed and less suitable for agriculture.
- Vertisols: rich in clay, these soils are capable of swelling and contracting, and are often

used for growing cotton and cereals.

- Sodic soils: found in the south-central and north-central regions, these sodium-rich soils can cause salinity problems.
- Hydromorphic soils: located in the far north of Burkina Faso, these soils are well drained but can become acidic over time.

Soil profile sampling

In order to monitor the different levels or layers of soil through which pollutants migrate, three (03) soil profiles were created between the tailings and between each tailing and the cyanide tank.

Figure 2. Map showing the location of pits or soil profiles.

Soil pit 3 is located halfway between the cyanide tank and tailings 1, in an area where gold panning is actively taking place. Soil pit 1 is also located halfway between tailings 2 and the cyanide tank, in the middle of a cornfield that is being invaded by gold panning activities. Soil pit 3 could not be placed halfway between tailings 1 and tailings 2. This is because the point where the pit should be located is occupied by waste rock from the old mine. It has been repositioned a little closer to tailings 1. It is located in an area of intense gold panning activity.

In the construction of the soil pits, fourlayer levels were identified based on color and coarse elements for each pit considered (RECORD, 2006). Pits 1.5 meters deep, 0.90 meters wide, and 1.5 meters long were dug. These different layers were sampled according to the model developed by Laperche, V. and Eisenlohr, L. (2001). A total of twelve (12) layers were identified, at a rate of four (4) layers per pit.

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.

RESULTS

Heavy metal content in soil profile horizons

Arsenic levels

The arsenic contents in the horizons of the soil profiles are shown in Figure 3. Except for the first horizon of the third soil profile, which has an arsenic content of 1,3 mg/kg, none of the horizons have an arsenic content. However, this content is below the threshold level for the Earth's crust, which is 1,5 mg/kg.

Figure 3. Arsenic content in the horizons (layers) of soil profiles (pits)

Cadmium levels

Figure 4 shows the cadmium content of soil samples in the different horizons of the soil profiles. Apart from the second horizon (layer) of soil profile 2, which recorded a high Cd content (296,3 mg/kg), no other horizon showed any Cd content. This cadmium content of 296,3 mg/kg obtained in layer C2 is well above that of the Earth's crust, which is 0,2 mg/kg.

Figure 4. Cadmium content in soil profile layers

Chromium levels

The results of the analysis of soil samples from the different layers of the soil profiles are shown in Figure 5.

In profile 1, there is a variation in content between the different layers. The highest content is observed in C2 and the lowest content is observed in C4, with respective values of 128.6 mg/kg and 1.6 mg/kg. Of the four horizons in profile 1, only horizon C4 has levels above the Earth's crust threshold of 70 mg/kg.

At profile 2, an upward trend in content is observed. All horizons of this profile have chromium contents that are above those of the Earth's crust.

In pit 3, an increase in chromium content is noted from layer C2 to layer C4, with respective values of 66,9 mg/kg (C2), 110,4 mg/kg (C3), and 276,8 mg/kg (C4). Layer C1 has a concentration of 81,4 mg/kg. Apart from layer C2, the other layers have concentrations above that of the Earth's crust.

Figure 5. Chromium content in soil profile horizons

Copper levels

The results of the analysis of samples from the layers of the copper soil pits are shown in Figure 6.

Regardless of the soil profile, copper content increased with depth. However, in profile 1, a notable decrease is observed between C3 and C4. The highest content is recorded at horizon 4 (C4) of profile 3 (pit 3) with a content of 121 mg/kg Cu.

Figure 6. Copper content in soil profile horizons

Manganese levels

The various results of the analysis of manganese content in soil samples from different layers of the soil pits are shown in Figure 7.

Manganese is present in all four horizons of the three soil profiles. The highest value is found in horizon 3 (C3) of profile 3, with 13827,7 mg/kg, while the lowest content is recorded in layer C4 of profile 1, with 3,8 mg/kg. Apart from layer C4 of profile 1, which has the lowest value (3,8 mg/kg), all other horizons have manganese contents higher than that of the Earth's crust (600 mg/kg).

Figure 7. Manganese content in soil profile horizons

Nickel levels

Figure 8 shows the nickel content in soil samples from different layers of the soil profiles. Analysis of the results shows an absence of nickel in layer C3 of profile 1 and layers C3 and C4 of profile 2. The highest Ni content is found in layer C3 of profile 3, with 300,9 mg/kg of Ni. It should also be noted that the different layers of profile 3 have higher Ni contents than the other two soil profiles.

Figure 8. Nickel content in soil profile horizons

Lead levels

The various results of the analysis of the lead content of soil samples from different layers of the soil profiles are shown in Figure 9.

The results show that lead is present in only two layers out of the twelve horizons. These are layer C4 of soil profiles 2 and 3, with 10,7 mg/kg and 3,2 mg/kg of Pb, respectively. However, none of these levels exceed that of the Earth's crust, which is 20 mg/kg of Pb.

Figure 9. Lead content in soil profile layers

Zinc levels

Figure 10 shows the zinc content results for soil samples from different layers of the soil profiles.

Zinc is present only in layer C2 of the second soil profile. The other two profiles show no zinc content in any horizon. Furthermore, the recorded zinc content of 0,3 mg/kg remains lower than that of the Earth's crust, which is 71 mg/kg Zn.

Figure 10. Zinc contents in soil profiles

Comparison of heavy metal content in soils in soil profiles

Normalizing the values of As, Cd, Cr, Cu, Mn, Ni, Pb, and Zn concentrations on a scale of 0 to 1 allowed for a comparison of contamination levels between soil profiles 1, 2, and 3 (Figure 11).

Profile 1 was found to be the least contaminated with metals overall. Most elements showed values close to 0 on the normalized scale, particularly As, Cd, Pb, and Zn. Concentrations of Cr, Cu, Mn, and Ni were present but remained relatively low compared to the other profiles.

Profile 2 showed an intermediate level of contamination. Several metals reached high values on the standardized scale, particularly Cd and Pb, which were close to 1. Cr and Zn also showed significant intensities compared to other sources.

Profile 3 stood out with the highest levels for several metals. These heavy metals (Mn, Ni, Cr, Cu, and As) reached values close to 1 on the standardized scale, indicating that it concentrates the relative maxima for these elements. Although some metals such as Cd and Zn are low in this profile, the high intensity of several major elements reflects a higher metal load in the other two pits.

Ultimately, the contamination hierarchy observed from the heat map was established as follows: profile 3, profile 2, then profile 1. This trend highlights a higher metal accumulation in profile 3, while profile 1 appears to be the least affected.

Figure 11. Comparison of contamination intensity between soil profiles 1, 2, and 3

Figure 12 shows a comparison of heavy metals between the three soil profiles (pit).

Arsenic (As) has very low levels in all profiles. It is practically absent in profiles 1 and 2, while a low average value of 0,33 mg/kg is observed in profile 3.

Cadmium (Cd) stands out due to its accumulation in profile 2 (74,07 mg/kg), while it is absent in profiles 1 and 3, suggesting sporadic contamination. As for chromium (Cr), concentrations are high in all three profiles, with 87,62 mg/kg in profile 1134,09 mg/kg in pit 2, and 133,88 mg/kg in profile 3. Profiles 2 and 3 show comparable levels that are higher than those in profile 1.

Copper (Cu) concentrations increase gradually from 37,48 mg/kg in profile 1 to 61,08 mg/kg in profile 2 and 82,64 mg/kg in profile 3. Zinc (Zn) levels are very low in all profiles, with a measurable value only in profile 2 (0,09 mg/kg), indicating a marginal presence.

Manganese (Mn) is the predominant metal. Its concentrations increase sharply from profile 1 (713,17 mg/kg) to profile 2 (1689,11 mg/kg), reaching a maximum in profile 3 (7349,53 mg/kg). This trend is accompanied by a wide dispersion of values, especially in profile 3.

Nickel (Ni) follows an increasing gradient, with 21,51 mg/kg in profile 1, 26,27 mg/kg in profile 2, and 185,22 mg/kg in profile 3. The high dispersion observed in profile 3 reflects significant accumulation. Lead (Pb) remains low overall, with no presence in profile 1, a concentration of 2,68 mg/kg in profile 2, and 0,8 mg/kg in profile 3.

Figure 12. Comparison by heavy metal in each soil pit

DISCUSSION

The study of soil profiles made it possible to examine the vertical migration of the various heavy metals studied. Most of the pollutants are concentrated in the surface layer (0-30 cm) in the immediate vicinity of the sources. Our results on the soil horizons affected by this pollution are consistent with those of Traore et al. (2014). However, there is one exception: manganese in profile 3, located between tailings 1 and the cyanide tank. In this profile, manganese contamination increases with depth. The vertical migration of this contaminant indicates a potential risk of groundwater contamination (Bouzahzahet al., 2014). This result highlights a dynamic dispersion of pollutants, characterized by areas of intense pollution and selective mobility of certain metals in specific locations. Targeted remediation measures and continuous environmental monitoring are necessary to mitigate the level of contamination from these identified heavy metals.

CONCLUSION

The soil at abandoned former mining sites, if not properly maintained or rehabilitated, becomes a dangerous source of environmental pollution. The chemicals used in mining (cyanide, acids, peroxide, etc.), and especially the various mining waste products, can be washed away by climatic (air and rain) and anthropogenic phenomena, leading to the leaching of various mining pollutants (cyanide and heavy metals). This leaching can lead to the generation of acid mine drainage (AMD) and contaminate soil, water, vegetation, and the ecosystem in general.

Analysis of the results obtained by analyzing the ETM content in the different horizons of the three soil profiles reveals that the highest concentrations are located in the 0 to 30 cm horizons. This finding reveals surface migration of metal pollutants through the topsoil horizons of the former mining site of Poura in Burkina Faso (West Africa).

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